REPORT OF THE

ACID RAIN PEER REVIEW PANEL

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EXECUTIVE SUMMARY

In January 1982, the Office of Science and Technology Policy asked Professor William A. Nierenberg, the Director of Scripps Institution of Oceanography, to assemble and chair a scientific panel on acid rain. He agreed and a panel of nine scientists was formed shortly thereafter. They were chartered to perform three tasks.

The first was to complete a peer review of the scientific basis relating to acid deposition in Eastern North America performed by three U.S.-Canadian scientific work groups. These bi-lateral studies were called for by the August 1980 Memorandum of Intent between the U.S. and Canada on transboundary air pollution. The peer review of each of these three studies is the subject of a separate chapter in this report.

The peer review finds the bilateral reports to be basically sound and thorough. The scientists reviewed a large amount of material, both published and unpublished, but there is a tendency toward recitation rather than synthesis and integration. The reports often depend too much on unpublished data, but this may reflect the growing but still incomplete state of knowledge.

Work Group I reviewed a huge amount of data, which was often incomplete or conflicting, in its long report. But its message was weakened considerably because it did not comply with its fundamental charge to

examine squarely the strength of the link between acid deposition and chemical and biological ecological changes. Work Group 2 produced a comprehensive series of reports but greatly overemphasized the present role of computer models for understanding long-range transport. Work Group 3B presented a large amount of data on emissions, control techniques and costs, but enclosed it in a report which is difficult to read and harder still to interpret.

The biggest failing of these reports was that the two parties of Work Group 1 were unable to agree on a preliminary acceptable deposition rate. In view of the importance of this subject and the feasibility of establishing a value (deductible from the MOI reports themselves), we recommend that Work Group 1 reconvene for this express purpose.

The second task the Panel was asked to perform was to provide further research and monitoring recommendations to reduce uncertainties in the scientific and technical knowledge regarding acid deposition. The panel finds that current scientific understanding of acid deposition is still highly incomplete. In order to begin to eliminate the major gaps most efficiently, it is recommended that highest priority be given to research on quantifying the effects of acid deposition (both wet and dry) on the total ecological system, distinguishing between the ecological effects of dry and wet deposition of sulfur and nitrogen, differentiating the environmental effects of acid deposition from those of natural stresses, measuring dry deposition at selected representative sites in eastern North

America, and applying tracer techniques on a broad scale to improve our knowledge of the source-receptor relationship. At lower-priority, research should include determining quantitatively the detailed mechanisms for the atmospheric oxidation of SO_2 and the oxides of nitrogen (NO_x), improved refinement of computer models of long-range transport, better data on emission of SO_2 and NO_x, evaluating new or improved control technologies for SO_2 and NO_x, and economic analyses of costs and benefits.

Up to 1984, the way in which the Federal Government conducted its research program on acid rain was disappointing. A greater portion of the funds should be allocated outside the Federal laboratories to attract new research groups, disciplines and approaches. Particular emphasis needs to be placed upon supportive research to understand the ecological consequences of both wet and dry acid deposition.

Finally, the panel was asked to provide an independent assessment of the uncertainties in available scientific and technical information on which recommendations of the U.S.-Canadian Work Groups are based. In response to this charge, general comments, findings, and recommendations concerning acid deposition that encompass policy matters as well as science were developed. Chapter III of this report contains these general comments. In summary, the panel views the acid rain problem as follows:

Acid deposition belongs to a socially very important class of problems that only appear to be precisely soluble by a straightforward sum of existing technological and legislative fixes. This is deceptive. Rather,

this class of problems is not permanently solved in a closed fashion, but must be treated progressively. As knowledge steadily increases, actions are taken which appear most effective and economical in the light of increasing understanding.

Large portions of eastern North America are currently being stressed by wet deposition of acids, by dry deposition of acid-forming substances, and by other air pollutants such as ozone, metals, and organics. Annual wet deposition of acidity in the northeastern United States and portions of Canada is at least 10 times that of remote areas. Acid deposition has altered the chemistry and biology of aquatic and terrestrial ecosystems of eastern North America. The principal agent altering the biosphere acidity is traceable to man-made sulfur dioxide (SO_2) emission. The Clean Air Act of 1970 has reduced the emission of SO_2 considerably, and may continue to do so. Nevertheless, the ecological problems that clearly result from man-made acid emissions are sufficiently well substantiated that additional reductions are required to prevent even more consequential environmental effects. The panel recommends that cost effective steps to reduce emissions begin now even though the resulting ecological benefits cannot yet be quantified.

There exist large uncertainties in every aspect of acid deposition -- emission, transport, transformation, and eventual deposition, interaction with the biosphere, and economic consequences. Nevertheless, when all the converging partial indicators are considered, it becomes clear that acid deposition is a problem for which solutions should be sought now, and further remedial steps taken.

ACKNOWLEDGMENTS

The panel wishes to express its appreciation to Mrs. Julie Rahn, a consultant to the panel, for her efforts in improving the readability and clarity of this document. Her many hours of work have made this report a cohesive whole, rather than the many separate pieces she started with.

Typing of the report and its many drafts, as well as logistics support for the October 1983 meeting, was provided by Mrs. Shirley Bonsell and her staff--Mrs. Judi Dubaldi, Mrs. Gail Rainey and Ms. Susan Romano--of the Science Research Laboratory at West Point.

Lastly, we thank Major John K. Robertson, Executive Secretary, for his time and work on behalf of the panel. His efforts in supervising production of drafts of this report, collating comments, proofreading, negotiating word changes, and attempting in vain to enforce deadlines are appreciated.

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I - INTRODUCTION

In January 1982, in anticipation of the March 1982 publication of the Work Group reports produced under the United States-Canadian Memorandum of Intent (MOI) on Transboundary Air Pollution, Dr. George A. Keyworth, II, Science Advisor to the President, asked Dr. William A. Nierenberg, Director of the Scripps Institution of Oceanography, to chair a panel to review the final MOI reports. After consulting members of the National Academy of Science and the National Academy of Engineering, Dr. Nierenberg nominated a panel of scientists and engineers to the task. In May 1982, Dr. Nierenberg approached the nominees and asked them to serve. The panelists, their institutional affiliations, and scientific disciplines are listed in Appendix 1.

In August 1982, formation of the Acid Rain Peer Review Panel was announced in the Federal Register. The charges in the charter given to the panel by the Office of Science and Technology Policy in that announcement are reproduced in Appendix 2.

Prior to its first meeting, the panel received the only MOI report in final form, that of Work Group 3B; the table of contents for each of the draft Work Group reports (1, 2 and 3B); the table of contents for any supplementary materials produced by the Work Groups; and the United States and Canadian membership lists for the Work Groups. (The organization and terms of reference of the MOI Work Groups are given in Appendix 3.)

The panel's first meeting in Washington, D.C. on 7 and 8 October 1982 consisted of background briefings by the United States co-chairmen and some American members of the three Work Groups. Dr. Keyworth addressed the

panel, reaffirming its Charter. Officials from EPA and the State Department also addressed the panel regarding coordination of the United States Work Groups and negotiation of the transboundary treaty. The Executive Director of the Interagency Task Force on Acid Precipitation briefed the panel on the task force's organization and mission. Because agreement seemed imminent on the Work Group 1 and 2 reports, the panel agreed to start reviewing the current draft reports of these groups.

Between the October meeting and a second meeting scheduled for 1 and 2 December 1982, draft final documents were obtained from the American co-chairmen of the Work Groups, copied and disseminated. The Work Group 1 report was marked by the Work Group to indicate which sections were still in question. A list of materials provided to panelists for review and background reading is furnished in Appendix 4.

Further meetings of the panel were held on 1 and 2 December 1982 in Washington, D.C., 27-29 January 1983 in La Jolla, California, and 2-4 June 1983 in Washington, D.C. These meetings were held to discuss the MOI reports, to plan the structure and content of the panel's report, and to begin writing drafts. In March 1983 the panel was provided with the final versions of the Work Group 1 and 2 reports, along with a list of differences between the final versions and the drafts they had been working with since November 1982. A final meeting was held in West Point, New York on 26-28 October 1983 to complete the rough draft of the panel's report. Successive drafts were mailed to panel members for revision from November 1983 to March 1984.

II - GENERAL COMMENTS ON THE MOI REPORTS

The panel is impressed with the efforts of the United States-Canadian Work Groups. They faced a monumental task in reviewing and integrating the vast amount of written material available on acid rain. Much of this material has not yet been published in the scientific literature and is available only as unreviewed monographs and technical reports by agencies of both federal governments and by industrial special-interest groups. Generally, the Work Groups have reviewed the material well, but in some areas we feel there has been overdependence on "soft" literature (writings which are not formally published, not peer-reviewed and not available to the general public, such as in-house reports, personal communications, and preprints).

We are disappointed that the two parties of Work Group 1 were unable to agree on a preliminary target loading for sulfate (SO_4^{-2}). The Work Group agreed that no ecological or chemical effects in sensitive fresh-water lakes and streams are observed when the sulfate loading (deposition) is less than 17 kilograms per hectare per year (kg/ha/yr). They also agreed that chemical and biological effects begin to be observed in these bodies at loadings of 20 and 30 kg/ha/yr respectively.

We know that it is not possible at this time to establish a precise loading below which the average sensitive aquatic system will be protected. The present loading, however, is at least 10 times greater in the Northeast than in remote areas of the world. We believe that this present loading is too high and that a target loading should be set.

If the figures that Work Group I agreed on are used, it would follow that a decrease to 30 kg/ha/yr would serve to eliminate damage to all but the most delicate of the fresh-water biological ecosystems. This is equivalent to a 25% reduction in deposition. We recommend that, given the degree of agreement to date, the two sides reconvene to develop an agreed preliminary target loading which can be used until better target loading values are available. We expect that the reassessment will recognize the large annual variability of the loadings as a normal effect.

The panel feels there was an overdependence on modeling, particularly by Work Group 2. This dependence on modeling is questionable in that the science behind the models is still not definitive, and proper data for verifying the models are not yet available. The extensive use of models may not be the responsibility of the Work Groups, but of those who defined the terms of reference for the Work Groups in the MOI.

The reports say little of dry deposition or of pollutants other than SO_2. The reports describe sulfur pollution in wet deposition as the predominant factor in acid deposition and acidification of our ecosystems. Little mention is given to co-pollutants, or the combined effects of multiple pollutants. Natural pollutants are ignored or mentioned in passing (granted, little is known about their amount or role). The reports are not well-rounded scientific documents (e.g., they do not assess conflicting data, gaps in knowledge, strengths or weaknesses in their conclusions, or alternate theories or explanations). Again, this may stem from the terms of reference given to the MOI Work Groups.

In the assessment of control strategies, material is presented which will allow workers to begin to assess the costs of controlling emissions and their effects (unit costs are presented, but no attempt is made at integration). On the other hand, the panel notes a complete lack of framework or any attempt at assessing the benefits of emission control, perhaps because of problems in assessing the value of natural ecosystems. The models for benefit-cost analysis presented in the MOI reports require data for both costs and benefits.

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III - GENERAL COMMENTS ON ACID RAIN

The United States and Canada together annually emit approximately 25,000,000 tons of sulfur dioxide and a comparable amount of nitrogen oxides. These oxides can be converted by atmospheric chemical processes into sulfuric and nitric acids (H_2SO_4 and HNO_3, respectively). The emissions are large enough to increase appreciably the acidity of natural rainfall. Rain in most of eastern North America is considerably more acid than expected from natural processes alone. The Clean Air Act of 1970 marked the formal recognition by the United States government of the importance of reducing emissions of sulfur and nitrogen oxides to the atmosphere. New power plants constructed since 1970 do control such emissions to lower levels. Such controls were a prudent first step, but have not accomplished all that was initially intended. We recommend that additional steps should be taken now which will result in meaningful reductions in the emissions of sulfur and nitrogen compounds into the atmosphere, beginning with those steps which are most cost-effective in reducing total deposition. Emission reductions are meaningful when they produce a detectable decrease in both acidic deposition and degradation of the biosphere.

An incomplete data base and sometimes contradictory interpretation of these data prevent the kinds of certainty which scientists would prefer. There are, however, many indicators which, taken collectively, lead us to conclude that acid deposition is a problem for which solutions should be sought. These indicators are as follows:

(1) In eastern North America, emissions of SO_2 and NO_x from human activities appear to be at least ten times larger than emissions from natural processes.

(2) A substantial fraction of such emissions returns as sulfate and nitrate (NO_3^-) in rainfall; a comparable amount returns as "dry" deposition through surface-interaction processes which are more difficult to monitor than "wet" deposition.

(3) In eastern North America the areas receiving the most-acid rain are found within and close to the major source regions.

(4) Acidity (sulfate and nitrate) in wet deposition is substantially greater in eastern North America than in areas without industrial activity.

(5) Acid precipitation contributes to the greater-than-natural hydrogen-ion levels in some lakes and streams in eastern North America.

(6) Although some kinds of lakes have been acid throughout their known history, others in areas subjected to acid deposition have become appreciably more acid during the past few decades.

(7) These changes in lake acidity have been accompanied by major changes in the biological activity within them, often including the disappearance of various aquatic biota, most visibly fish.

(8) The largest of such aquatic effects have occurred in "sensitive" regions, in which acidity is not "buffered" by the presence of alkaline minerals.

(9) Large areas of eastern North America have been identified whose geologic composition is characterized by the absence of any important buffering capacity.

(10) Forest damage has been increasing in eastern North America during the past few decades; acid deposition may be a contributor.

The overall scientific understanding of the various aspects of acidic precipitation is incomplete at the present time, and will continue to

have major uncertainties well into the future. Some of these gaps in our knowledge are permanent because the necessary measurements were not made ten, twenty, or fifty years ago; the potential future utility of such information was not yet recognized. Other gaps exist because the needed scientific techniques have not yet been perfected or have not been adapted to the scale required for measurements covering much of the entire Western Hemisphere. Some of the important information will require at least ten or twenty years of additional data collection to take full cognizance of atmospheric variability and atmospheric cycles. Biological systems are extremely complex and variable. Response and recovery of many of these systems to external stress will require long-term (decades) detailed study for full evaluation. For these reasons, any current scientifically derived recommendations must be based on an imperfect, but always increasing, body of pertinent data whose quality and completeness can be expected to improve for decades. Recommendations based on imperfect data run the risk of being in error; recommendations for inaction pending collection of all the desirable data entail the even greater risk of ecological damage.

The chemical processing of SO_2 and NO_x into acids in the atmosphere potentially involves a very large number of chemical reactions, whose relative importances change drastically with time and location, often in response to varying meteorological conditions. Sulfur and nitrogen can be removed from the atmosphere in various chemical forms, and by both dry processes at the surface and wet processes in rainfall. Measurements of SO_4^{-2} and NO_3^- in rainfall are now widespread, but do not have a long historical base. Measurements of dry deposition are so scattered (and of questionable validity) that quantitative assessment is essentially not possible even now.

Modeling of atmospheric emissions, transport and deposition has been confined almost entirely to the sulfur cycle, leaving nitrogen and other pollutants to the future. The existing models do not agree with one another, and cannot be verified by good field data because such data are scarce. The models do not even reproduce well the observations on gaseous SO_2 that are available. Models cannot be relied on to estimate how much material emitted at one place will be deposited in another, or how much SO_2 will be converted to H_2SO_4 before deposition.

There exists now no acceptable method for determining source-receptor relationships on a scale much smaller than "eastern North America". With a very large effort in laboratory atmospheric chemistry, field measurements, and atmospheric modeling, it might be possible within ten years (but certainly more than five years) to produce a verified source-receptor model for eastern North America. We have great hope that methodology based on natural tracers in fossil fuels may bypass some of these difficulties and perhaps reduce the time needed to elucidate this complex of problems. Even if a verified model is developed in the future, the source-receptor relationship may be found to be sufficiently complex and variable that emission controls would still need to be assigned over large areas rather than locally.

Reducing present SO_2 emissions would reduce deposition of total sulfur, and, consequently, both reduce the probability of major degradation of additional acid-sensitive lakes or forests and allow anthropogenically acidified areas to begin to return to their original biological condition.

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The effects of acid deposition on biological systems in North America range from certain to speculative. There is no question that fresh water bodies in sensitive areas have been altered. At high concentrations, acidity can release, or "mobilize", aluminum from solid minerals; this may lead to toxic effects on biota in both lakes and forest soils. While there is strong evidence for damage to limestone monuments, bridges, buildings, and other structures from SO_2 and other corrosive gases, there is no good estimate of the economic magnitude of these effects or of the contribution from acid deposition. The effects of air pollutants and acid deposition on agriculture may be important but quantitative evidence is scanty.

Lakes and streams may require years or decades to recover from anthropogenic acidification once the acidic inputs are removed, with the recovery time depending on local geochemical factors, flushing rates, rates of species colonization, extent of alteration of trace-element composition, and other factors. In contrast, recovery times for stressed terrestrial ecosystems are decades to centuries. At its simplest level, this difference in recovery times arises because the major photosynthetic organisms in aquatic environments are relatively short-lived compared to trees. There are, however, many other complex differences between the two types of systems.

We are especially concerned about real and potential changes in the chemistry and biology of soils in nonagricultural areas (i.e., unmanaged soils). Because soils need hundreds to thousands of years to develop, they will recover very slowly from anthropogenically induced changes unless artificial amendments such as lime are used.

Soil microorganisms may be particularly sensitive to changes in acidity; this fundamental part of the biological cycle is responsible for cycling nitrogen, carbon, phosphorus and other essential nutrients through the food web. For example, the entire biosphere depends on proper functioning of denitrifying microbes. Although evidence that increased acidity is perturbing populations of microorganisms is scanty, the prospect of such an occurrence is grave. Biogeochemical changes in soils appear to be particularly long-term. It may take years or even decades of accumulation of acidity and other toxic airborne pollutants before consequences can be observed. It may take at least that long for the soils to revert to their original condition. It is this aspect which gives us the greatest concern.

Acid deposition belongs to a socially very important class of problems that appear to be precisely soluble by a straightforward sum of existing technological and legislative fixes. This is deceptive. Rather, this class of problems is not permanently solved in a closed fashion, but is treated progressively. As knowledge and understanding steadily increase, actions are taken which appear most effective and economical at each stage.

Actions to reduce acid deposition will have to be taken despite incomplete knowledge. We have earlier estimated how long it may take to understand "wet" atmospheric chemistry or the biological response to acidity. Reasonably accurate models incorporating relevant meteorology, chemistry, mineralogy and biology will take even longer. Yet, if we wait until scientific knowledge is definitive, recovery times may have increased to decades or a century or more (for mature forests and soils).

We feel that the proper initial approach is to begin immediately with the most economically effective steps for reducing acid deposition. Control costs appear to range widely, especially for sulfur removal; some steps can be much more cost-effective than others. Some of the most economically efficient means for lessening sulfur emissions in eastern North America and other sensitive areas are intensifying coal washing and placing initial controls on nonferrous smelters; switching to fuel of lower sulfur content during summer (when most sulfuric acid is deposited) might lessen the overall deposition in distant regions without necessarily changing annual emissions. Other control technologies are often more expensive, but research is steadily decreasing their cost.

IV - RESEARCH RECOMMENDATIONS

It is critical that new funds be made available both to initiate additional studies and to continue and expand present studies.

There are four general areas of uncertainty for quantitatively understanding how and to what extent anthropogenic emissions of SO_2 (and NO_x) may damage ecosystems:

A. Magnitude of anthropogenic emissions and their relation to natural emissions.

B. Chemistry of conversion of SO_2 (NO_x) to sulfuric (nitric) acid in the atmosphere, in precipitation, and after dry deposition.

C. Transport of acid and its precursors from sources to points of deposition.

D. Present and potential ecological consequences of the deposition.

By far the largest quantitative and even qualitative uncertainties exist in the fourth category, (D), which is the most complex because of the large number of components and their variabilities. It also has been the least adequately supported with research funds, especially in the area of effects on unmanaged soils, wetlands, and forests. This fourth category is the most important to the acid rain problem, because ecological consequences are the raison d'etre of the problem. At present, the need for quantitative description or precision in the other three areas is much less urgent. Unfortunately, acquiring quantitative and decisive information in this fourth category will take at least a decade of careful field and laboratory study.

For these reasons, we suggest the following order of priorities for research support:

1. We give highest priority to quantifying the effects of acid deposition, both wet and dry, on the total ecological system, including natural and managed vegetation, soil, and ground water. Of special importance may be effects on microbial activity in soil and wetlands and, through that, on the nitrogen cycle.

These investigations should include laboratory and field studies as appropriate on:

1) Detailed ecosystem analyses on a variety of terrestrial watersheds, including associated lakes and streams. These studies should determine the relative inputs of H^+, SO_4^{-2}, and NO_3^- from direct deposition and from biological and chemical activities within soils, lakes and lake sediments. The studies should include landscapes containing clear-water lakes, brown-water lakes, and streams. Although the studies should concentrate on eastern and north central states, they should include sensitive areas in other parts of the country. These ecosystem studies should also emphasize:

a) Effects on vegetation and soils. Detailed studies are urgently needed on direct and indirect effects of acid precipitation on vegetation and soils of managed (i.e., agricultural) and unmanaged (i.e., forest) systems. These studies should be long-term, so they can include the natural variability in climate and biological response.

b) Biogeochemical processes, including effects of acidity and metals released by acidity on microorganisms which process nutrients and organic material in soils, lake sediments, rivers and, most importantly, fresh-water wetlands; the effects of acidity on geochemistry of the soil; and mechanisms controlling the chemistry of drainage waters.

c) The relative effects of natural and anthropogenic sources of acidity.

2) Physiological bases of toxicity from acid and dissolved aluminum. We are approaching an understanding of the mechanisms of acid toxicity on fish, but relatively little is known about the physiology of acid toxicity on other aquatic and terrestrial organisms, plants in particular. Moreover, at least in field studies, it is clear that acid and aluminum may act

synergistically. Their individual physiological effects should be distinguished by laboratory studies. Effects of calcium, humate and fulvates on the uptake of metals should be an important part of such research. Liming may actually increase the toxicity of aluminum dissolved by the acidified water and then complexed by dissolved organic carbon. Liming precipitates the dissolved organic carbon and leaves the aluminum in a more toxic ionic form. The generality of this occurrence should be investigated because it affects the utility of liming as a countermeasure to lake acidification.

3) Study of historical trends in lakes and bogs. To evaluate the temporal trends of acidity in lakes from various parts of the country, cores taken from the bottom of lakes should be analyzed for shifts in species in the watershed (by pollen analysis), shifts in chemistry of the water and sediments, and shifts in organisms in the lake (diatoms, desmids, chironomids, cladocerans, fish). Bogs and lakes should be selected from the entire East, the upper Midwest, and various parts of Canada. As part of these studies, the identities of the species must be verified and voucher specimens must be kept. Long-term experimental studies in natural ecosystems should be initiated to provide a basis for interpreting existing sediment profiles.

4) Extended data bases. Lakes and streams in the northeastern United States are clearly being affected by acid rain. Before such effects become severe in other parts of the country (e.g., southeastern United States), the extent and severity of the problem should be surveyed. Teams of scientists should examine the condition of sensitive surface waters throughout the United States, including clear, poorly buffered waters at relatively high altitudes. These studies should include analyses for pH, Ca^{+2}, Mg^{+2}, SO_4^{-2}, NO_3^-, dissolved metals and alkalinity, and should continue for at least a decade.

5) The effects of reduced emissions should be quantified by carefully designed ecological studies and monitoring programs.

2. Quantifying the relative effects of dry deposition of acid precursors (SO_2, NO_x) vs. wet deposition of acid onto a given ecological system. Because dry deposition should dominate over wet deposition in many regions, it is important to know how relevant the form of deposition is to ecological systems. For example, how much difference does it make whether sulfur is adsorbed as SO_2 by a soil (whose surface is often wet) or deposited as sulfuric acid in precipitation? This question can probably be answered before the full effects of acidification are understood.

3. Natural vegetation is stressed by a variety of agents acting separately or together. Some, such as droughts, are independent of SO_2 and NO_x emissions. Others are associated with these emissions and acid deposition. It is important to have laboratory data and particularly field observations directed toward disentangling the effects of acid deposition from those of other anthropogenic atmospheric insults (especially O_3, SO_2 and toxic trace elements), drought, pests, and plant diseases.

4. Next, but much less important, would be a reliable relation between emission of SO_2 and NO_x in one region and deposition of these gases or the acids derived from them in another region. Models do not yet give such information and are unlikely to do so before a sufficient data base is acquired with respect to which models can be tested. For dry deposition, which may be as important as wet deposition (only one-fifth of the SO_2 emitted in eastern North America comes down "wet"), there is not even a full year's data for any natural ecosystem. Therefore, developing and implementing methods for carefully measuring dry deposition at a limited number of regionally representative sites in eastern North America is particularly important for verifying models and predicting ecological effects. As a complement, more monitoring data on SO_2 and NO_x in rural areas are needed. These data should also lead to improved sulfur and nitrogen budgets for eastern North America.

5. Understanding of transport also may profit greatly from network measurements of tracers (elements, compounds, stable isotopes) presently emitted continuously (or perhaps artificially inserted tracers), because relative abundances of certain tracers can uniquely characterize area and point sources of SO_2 and NO_x. Both of the above measurement programs

(4 and 5) appear to us more urgent at this time than expanded efforts in constructing mathematical models, which can be verified only by comparing them with data which do not yet exist.

6. Next in importance is understanding the atmospheric chemistry by which SO_2 and NO_x are acidified before they are deposited by precipitation. The importance of such information depends upon the answers to priorities 2 and 4. Thus, if the ecological consequences and transport ranges were shown to be insensitive to degree of conversion to acid, it would not be particularly important to determine the details of atmospheric oxidation. But if, for example, sulfuric acid deposited in precipitation were found to be potentially harmful, the atmospheric chemistry of SO_2 conversion would become very important for verifying models and (more significantly) for selecting the best control strategies. (For example, would it be easier to control oxidants or SO_2 to reduce wet deposition of sulfuric acid?) Necessary to understand quantitatively the atmospheric transformation to acid would be field programs in cloud chemistry (especially on the surface of and within droplets) and oxidant measurement (especially H_2O_2, and probably O_3 and oxidant precursors) at droplet altitudes. Laboratory experiments should include mechanisms of oxidizing SO_2 and NO_x, as well as isotopic fractionation of ^{18}O in sulfate as a function of SO_2 oxidation mechanisms and isotopic composition of reactants (for comparison with field data on ^{18}O in rainwater, sulfate, and cloud-droplet oxidizers such as H_2O_2).

7. The information resulting from priorities 4 through 6 should then be incorporated into improved computer models. (One purpose will be to decide whether the improved models perform significantly better than the

original ones did.) A key question involving both chemistry and meteorology is the degree of linearity between SO_2 emission and eventual wet and dry deposition, but a precise answer is not achievable now because of insufficient data.

8. Although emission data for SO_2 and NO_x can be improved, their accuracy is already much better than for deposition; however, better emission data on alkaline particles and oxidant precursors may be useful. Natural sources of many species still need to be characterized more thoroughly.

9. Engineering research on ways to remove sulfur at the source should still be supported by federal and industrial agencies.

10. The main applied purpose of the scientific understanding which could be advanced by these programs is to inform those who decide upon control strategies. To a great extent, optimal strategies must await such understanding. Some important relevant information, however, may be obtained now from improved economic analyses on:

a) Cost of material damage from SO_2 emission.

b) Cost of altered yields of agricultural crops from SO_2 and O_3.

c) Future SO_2 and NO_x emissions with more realistic projections of electric-power use, retirement of old generators, steel production, coal vs. oil, etc.

d) Costs of using low-sulfur fuels when season (e.g., summer) or frequency of precipitation favors wet deposition of acid.

e) For each SO_2 source, one should determine the lowest-cost approach for removing increasing amounts of sulfur.

f) What kind of legislation would result in least cost to society for a given total emission reduction? For example, if one assumes that sulfur emitted from one source is ecologically equal to that from any other, what would be

the consequence of allowing a free-market sale of limited pollution rights for SO_2?

We are disappointed at the way in which the Federal Government has been conducting its research program on acid rain. A much larger share of the research should be given to non-Federal laboratories. In addition, we feel strongly that highest priority be given to the most creative ideas and innovative approaches.

We realize that the Federal Government and other agencies are supporting important ongoing research on acid deposition. At the same time, however, imbalances exist, with some areas seriously underfunded. One example is ecological effects, where a relatively modest increase in support (several million dollars annually) would have disproportionately great results. Although current funding of acid rain studies is much higher than in the past and increasing, carefully chosen priorities in fields and investigators can markedly accelerate progress in this difficult field.

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V - REVIEW OF WORK GROUP 1 REPORT - IMPACT ASSESSMENT

Introduction

Large areas of eastern North America are currently being stressed by wet deposition of acids, by dry deposition of acid-forming substances, and by various other air pollutants such as ozone. The panel has concluded that acid deposition has altered aquatic and terrestrial ecosystems of eastern North America both qualitatively and quantitatively. Perhaps the best known of these changes is that numerous recently acidified lakes in the northeastern United States and southeastern Canada no longer contain viable populations of some species of fish.

Work Group 1 was charged with reviewing the past, present, and projected impacts of transboundary transport of air pollutants into sensitive receptor areas in the United States and Canada. In addition, Work Group 1 was to estimate the number of years remaining until the sensitive areas were affected significantly, and to propose the amount of reductions in deposition of the pollutants on various time scales that would be required to protect these areas.

Work Group 1 produced a final report which was very long--626 pages of text. Most of this length was due to the large amount of evidence reviewed. But part of the length came about because the Canadians and Americans could not agree on certain sections and issued them separately, and because the Work Group went well beyond its charter by including extra chapters on damage to man-made structures, methods to estimate benefits from controlling transboundary transport, an inventory of natural resources, and liming.

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In the sections below, we first offer general remarks on the report as a whole, and then deal with each chapter individually.

General Remarks

Perhaps the greatest strength of this report is the amount of evidence presented for relatively recent chemical and biological changes in natural ecosystems in parts of North America remote from urban or industrial centers. The evidence is convincing--something is happening. Some of these changes may be natural, because ecosystems are not always static. But the report offers massive evidence that air pollutants are associated with many of these changes. The report documents clearly that high levels of acidic deposition are linked with ecological changes in parts of eastern North America. In areas with less deposition, similar changes are weaker or absent altogether.

But is the link to air pollution causal or coincidental? In some cases, such as ozone and vegetation or sulfur dioxide and man-made structures, it is definitely causal, and the report says so. In the case of acid deposition and ecosystems (the major concern of the entire Memorandum of Intent), however, the degree of causality is drawn much less clearly. To be sure, whole-lake and stream acidification experiments in Canada and the United States have shown that systematic, widespread, and reproducible chemical and biological changes occur as pH drops below about 5.5. Similar changes are observed in numerous lakes and streams which have been acidified recently.

This is not direct evidence of causality, however; it is only circumstantial evidence. In our view, the crux of the acid precipitation

debate is the strength of the link between acid deposition in a given region and ecological changes in that region. The fundamental charge of Work Group 1 was to address this point in detail, by documenting the past, present, and future adverse effects of transported and deposited air pollutants.

Work Group 1 did not meet this charge fully. Commendable as its Final Report is, it dwells too much on data rather than on ideas, and on individual relations rather than on the big picture. Too much of the material is not digested; critical issues are hedged or obfuscated rather than met squarely. The terms of reference demand clear statements; the Work Group often neither offered them nor noted their absence. This failure to deal directly with some of the most important questions is the greatest weakness of the Final Report.

We recognize fully that the environmental effects of acid deposition (and of ozone and other transported pollutants) are exceedingly complicated and not amenable to any simple description. Nevertheless, brief statements of the current understanding are required by decision-makers, and are extremely important to the concerned public as well. We feel that Work Group 1 could and should have summarized its findings much more succinctly than it did.

Consider aquatic effects, for example. Although it is presently not possible to <u>prove</u> that acid deposition has changed the chemistry or biology of aquatic systems in eastern North America (absolute proof of causality is usually impossible in science), an extremely convincing argument can be made. Recently acidified lakes and streams are found only where there is

acid rain (not in the Sierra or Cascade Mountains, the Boundary Lakes Area of northern Minnesota, or northern Scandinavia, for example, even though these areas are environmentally sensitive). In recently acidified lakes, the dominant anion is sulfate, as it is in acid rain. Elevated sulfate is found in most surface waters throughout eastern North America and southern Scandanavia, even in those not yet acidified. In non-acidified lakes the dominate anion is usually bicarbonate. In lakes near very strong sources of sulfur dioxide, such as the smelters of Sudbury, Ontario, ecological effects have been severe. Thus, there can be no doubt that high loadings of acid can destroy the normal biology of a lake.

But what about the majority of the lakes, which are subject to more typical rates of acid deposition? At present, the percentage of these lakes affected chemically or biologically is not known. (In fact, the total number of lakes in eastern North America is not known.) Of the known lakes, only a tiny percentage has ever been studied, and only a tiny percentage of these studies has systematically surveyed the ecological changes. Thus, we are dealing with an enormous deficit of data relative to the potential importance of the problem.

One point is certain--it is very difficult to generalize about lakes and their response to acid deposition because the response of a lake depends on factors such as its underlying geology, nearby vegetation, size and depth of the lake, nature and depth of surrounding soils, relative area of lake and watershed, and other factors, all of which vary over large ranges. Thus, a population of lakes should respond in a great variety of ways to a given amount of acid deposition, and that is exactly what is seen in eastern North America.

At high elevations in the Adirondack Mountains, where soils are thin, minerals are resistant to weathering, and lakes are poorly buffered and receive heavy loadings of acid, a large fraction of the lakes is already acidified. At lower altitudes, some lakes are acidified, some are being titrated, and others show no effects of acidification. Some large lakes, such as Erie and Cayuga, are basic and will remain so indefinitely because of their size and buffering. Other large lakes, however, such as Honnedaga in the Adirondacks, are already quite acidic (pH < 5.0) because of the small size of the watershed relative to the lake (only 4:1); thus, the water in the lake is largely rainfall, with minimal alteration by soils in the watershed. A "typical" nonacidified New England lake may have a pH above 6 because it contains small amounts of bicarbonate, but sulfate has become the dominant anion. And so it goes throughout the spectrum of lake response to acid deposition.

As a lake receives acidity, its alkalinity first decreases (the titration phase), then disappears altogether, after which the lake acidifies rapidly. It is now known that biological effects occur throughout the titration phase, not solely after the lake is acidified. (By acidified, we mean having reached a pH of lower than about 5.5).

In summary, then, lakes do not have to be acidified to be acidifying, and may show biological effects well before they are acidified. For the reasons given above, lakes in a given area will follow highly individualized pathways toward acidification. Some may never become acidified, some may already be acidified, and many will be somewhere in between. Others, the so-called "brown-water" lakes, are naturally acid from organic acids, and hence are not as directly affected by contemporary

acid deposition. (All lakes in the eastern United States have some amount of humate.) With such variety available in the lakes of a given region, exceptions can be found for any statement. These exceptions are expected, however, and should not be overemphasized in developing the total picture.

Our last general remark on the Final Report of Work Group 1 concerns our mixed feelings regarding the extra chapters on additional topics. On the one hand, the effort and concern behind them were commendable. On the other hand, we regret any time they took away from dealing with the central issues.

Remarks on individual chapters

Aquatic Impacts

The chapter on aquatic impacts takes up nearly half the Final Report, and rightly so, because this aspect of acid deposition is one of the most important and complex. In our view, the huge mass of material on aquatic effects was covered well by Work Group 1. As noted above, there was a certain lack of synthesis throughout, which greatly weakened the force of their message.

One very important aspect of aquatic effects which could have been treated more fully in this chapter is the general confusion between the various types of naturally acid surface waters. There are three distinct types. The first type has high concentrations of organic acids, is often yellow or brown in color, usually contains growths of Sphagnum, and normally has a pH below 5. The second type results from volcanic activity: these waters are high in mineral acids and can have pHs below 4. (This second

type does not occur in eastern North America and will not be discussed further.) The third type contains clear water and is found over granite or sand; these waters have very low conductivity, poor buffering, and pHs of 5.6 to 7.0.

The first type, the brown-water lakes and streams, have been naturally acid for thousands of years, yet much of the literature on these lakes and streams was not considered. In these waters, dissolved aluminum and other toxic metals are low in concentration and are complexed by the dissolved organic matter and thereby rendered nontoxic to organisms. As a result, brown-water lakes and streams may support thriving communities of plants, animals, and microbes. In contrast, the recently acidified waters are normally derived from the third type listed above. Their major acids are mineral (e.g., H_2SO_4 and HNO_3), and their concentrations of dissolved organic matter are low. At low pH, dissolved metals such as aluminum exist in inorganic forms which may be quite toxic to organisms. These acidified lakes and streams have depleted populations of plants, animals, and microbes. It is these acidified waters and aquatic effects that are of concern relative to acid rain.

Much of this aquatic chapter was devoted to reviewing effects of acid deposition under controlled or laboratory conditions. A clearer demarcation between laboratory results and symptoms noted in real ecosystems would have been desirable. It is easy for the reader to confuse potential effects with actual ones.

The different fates of hydrogen and sulfate ions in watersheds was properly stressed in this chapter. While more than 80% of the acidity is

absorbed, even by the less-buffered granitic soils, this is not the case with sulfate which reaches the lakes and streams in much higher proportion.

Perhaps the most important aspect of the aquatic chapter needing comment is the failure of the American and Canadian members to agree on a value for target loading, or rate of deposition of sulfate necessary to protect sensitive ecosystems in eastern North America. Separate summaries issued by the United States and Canada for the aquatic chapter represented the only area of the entire MOI process in which the two countries officially disagreed. Careful reading of these summaries convinces us, however, that the the American and Canadian delegates were actually quite close on target loadings, but had many other differences of opinion about aquatic effects. The American summary consistently stressed the gaps and uncertainties in the data and the consequent difficulties in drawing conclusions from them, whereas the Canadian summary consistently stressed that much of importance could be concluded from the available data. The present data document large-scale chemical and biological effects of acid deposition on non-brown-water lakes in eastern North America. These effects are numerous and severe enough to warrant mitigation of SO_2 and NO_x from anthropogenic sources.

Terrestrial Impacts

This chapter is not as comprehensive as the one on aquatic impacts. The literature is not covered as well, especially in the sections on forests and soils. This is unfortunate, because terrestrial effects of acid precipitation may be extremely important, and may rival or exceed those in surface waters. Laboratory experiments have shown that acid

deposition adversely affects both plant growth and foliage. In the natural environment, however, the effects are not so clear because acid rain is only one of several stresses on plants, some others being ozone, SO_2, metals, and droughts. Also, it is often difficult or impossible to distinguish effects of direct deposition to the exposed plant from effects of increased ground-water acidity or leaching of essential micronutrients on root systems.

Another important terrestrial effect of acid deposition may be on cycling of nutrients by bacteria, blue-green algae, and fungi. For instance, pHs of 3.2 inhibit mineralization of glucose in soils, pHs of 3.0 to 4.0 reduce decomposition of plant litter, and pHs below 6.5 decrease sulfur reduction in soils. Because cycling of nutrients is such a critical function of the biosphere, any adverse effect could be significant. More research in this area is needed, particularly in wetlands, lake and river sediments, and terrestrial soils.

Lichens are apparently quite sensitive to SO_2. In some areas, they have merely been depleted; in others, the species have changed. Agricultural plants are sensitive to acid deposition in the laboratory, but effects on actual crops are much less clear, possibly because most crops are annuals and are fertilized routinely. Some recent field experiments, however, have shown large decreases in yield. Forests might be expected to show more clear-cut effects of acid deposition, because trees are perennials, are usually not fertilized, and often grow in soils whose levels of nutrients are low. Although forests in numerous areas receiving heavy loadings of acid are growing less rapidly now than earlier, it is very difficult to ascribe these changes uniquely to acid deposition. More

recent data from Germany (not reviewed in the Final Report) have suggested that acid deposition affects forest growth significantly and support the conclusion that the major effect is on roots, not foliage.

Acid deposition probably does not affect terrestrial wildlife directly, but may influence it indirectly via decreased plant growth or contamination by metals. Soil bacteria and fungal microrhizae may also be affected by acidified soils; because both are important in cycling nutrients through terrestrial ecosystems, affecting them would affect the entire ecosystem.

It is still difficult to estimate economic effects of acid deposition on the terrestrial biosphere. It is also not yet possible to map forest sensitivity to acid deposition. Nevertheless, it appears that acid deposition has increased rates of podzolization in forests of eastern North America. Such changes are extremely rapid in the context of historic soil development and thus represent an important alteration of the biosphere.

Human health and visibility

In general, this chapter is done well. We accept the assertion that acidic deposition does not directly affect human health. Even indirect effects such as increases in aluminum or lead in water supplies appear to have no immediate health effect, although they should be monitored.

On the other hand, degradation of visibility by fine-particle acidic aerosol is real and widespread. While it is true that its effects show up most clearly in the West, where virtually unlimited visibility surrounding scenic vistas is expected, we differ from Work Group 1 on the relative

importance of visibility there. Preoccupation with the West is largely cultural. Eastern North America has many regions with great vistas which are widely valued when seen. When weighted for the larger number of people in the East, we believe that maintaining visibility there is at least as important as in the West. Once one becomes attuned to atmospheric optics, reduced visibility can be just as annoying over distances of 5 miles as over 150 miles.

Man-made structures

In our view, this chapter is not required by the terms of reference of Work Group 1. It is interesting, however, and possibly important, because cultural relics as well as modern structures are being corroded by atmospheric chemicals. This chapter points out, however, that most of the damage to materials is probably caused by corrosive gases generated locally rather than by regional pollutants or deposited acidity. SO_2 (in combination with adsorbed water) is the most important corroding agent, followed by NO_x and ozone.

Methodologies for estimating economic benefits of controls

We consider this chapter to be of limited value. Its basic problem lies in the first sentence of the summary: "Traditionally, the decision-making process has required an appreciation of the costs and benefits associated with following a prescribed set of actions." The benefits of a properly functioning ecosystem are much more than matters of dollars and cents, and are often not appreciated by people unfamiliar with ecology. To a large extent, our clean air and clean water depend on

ecological cycles. Unfortunately, the inherent worth of an ecosystem, its components, or the benefits associated with their maintenance can not yet be expressed in terms of pure economics, nor are they liable to be in the foreseeable future.

Thus, we feel that this chapter is not helpful at the present time. We also feel that its statement that current benefit-cost analyses must "either omit real but intangible benefits or include a wide uncertainty range" is overly bland and fails to deal with the real point of the relevance of economics to ecological protection.

Resource inventory

In our view, the major result of this chapter is that it is presently impossible to evaluate our natural resources accurately. In the words of Section 1.7.1, "The completion of this inventory has served to underline the considerable weakness which exists in our ability to adequately quantify the extent of the resource at risk." We agree.

Liming

We share with Work Group 1's mixed feelings about liming. It is a temporary solution which should be applied as sparingly as possible in as few locations as possible. Before wholesale liming is undertaken, careful field studies of its aquatic effects are needed.

Did Work Group 1 meet its terms of reference?

Work Group 1 was given eight specific terms of reference. We now review each of them.

"identify and assess physical and biological consequences possibly related to transboundary air pollution" This was met well, for both pollutants such as ozone and deposition of acidity.

"determine the present status of physical and biological indicators which characterize the ecological stability of each sensitive area identified" We are not sure whether the intent of this term of reference was to evaluate the inherent stability of sensitive areas of eastern North America (ecological stability is currently a controversial topic) or the actual extent of changes in the various areas. Work Group 1 seems to have addressed the latter reasonably, but not the former. Sensitive organisms and their disappearance were treated in some detail.

"review available data bases to establish more accurately historic adverse environmental impacts" Work Group 1 evaluated historic trends in ecosystems at least as well as had been done previously, if not better. Brown-water, humate-rich lakes and streams, however, which would have rounded out their analysis, were ignored.

"determine the current adverse environmental impact within identified sensitive areas-annual, seasonal, and episodic" This represents an enormous undertaking. This term of reference embodies the ultimate goal of all studies about effects of acidic deposition. Were the answer known, a precise program of controls could be begun with full confidence. Work Group 1 tried, but the two countries diverged concerning the dose-response curve for deposited acidity. In actuality, there are as many dose-response curves as there are water bodies and ecosystems. Some cases are known accurately, but many more cases are completely unknown, and will remain so for many years.

"determine the release of residues potentially related to transboundary air pollution, including possible episodic release from snowpack melt in sensitive areas" Work Group 1 dealt satisfactorily with melting of snowpacks, but did not consider any other residues in detail.

"assess the years remaining before significant ecological changes are sustained within identified sensitive areas" Work Group 1 did this only poorly, but it is exceedingly difficult to do at all. It demands the history of every ecosystem of interest from which to develop models for testing. Considering that every lake in eastern North America responds individually to acid deposition, and even though helpful groupings can be made, to perform this task quantitatively presents a formidable challenge even for the next hundred years.

"propose reductions in the air pollutant deposition rates-annual, seasonal, and episodic-which would be necessary to protect identified sensitive areas" Work Group 1 tried this only for annual rates, and could not agree on the value.

"prepare proposals for the "Research, Modelling and Monitoring" element of an agreement" This was done satisfactorily.

In summary, Work Group 1 met three of the eight terms of reference well, two partially, and three poorly. It seems to us, though, that the failure to meet certain terms of reference was mostly a consequence of the difficulty of the terms of reference.

VI - REVIEW OF WORK GROUP 2 REPORTS - ATMOSPHERIC SCIENCES AND ANALYSIS

Work Group 2 produced a Final Report (2F) and four supporting technical papers:

2F-A Atmospheric Sciences Subgroup Report

2F-M Regional Modeling Subgroup Report

2F-I Monitoring and Interpretation Subgroup Report

2F-L Local and Mesoscale Analysis Subgroup Report

The first section below discusses some of the major topics dealt with in these reports. The next section offers remarks on the individual reports themselves. The last section considers whether Work Group 2 met its terms of reference.

Remarks on Specific Topics

Items of Concern

In general, the reports of Work Group 2 are carefully done and credible, and give a fair and balanced account of the state of current knowledge of many meteorological and chemical aspects of acid deposition as of 1982. A great deal of effort was obviously put into them.

Nevertheless, we have reservations about certain portions of these reports. The specific topics in question are the emphasis on modeling, the modeling of sulfur only, the lack of data on dry deposition, and the treatment of the linearity question.

Our greatest concern is the emphasis placed on modeling--at the expense of traditional scientific approaches--to deduce the relative

importances of local and distant sources of sulfur in air and in deposition. When Work Group 2 was formed, it was widely expected that transport models could be developed to derive such source-receptor relationships. The reports make it abundantly clear, however, that the models failed to furnish reliable source-receptor relationships. The creation of the Subgroup on Monitoring and Interpretation partway through the work was an attempt to restore a balance between models and the more traditional approaches, but it seems to have been too little and too late.

We feel that Work Group 2 concentrated too heavily on sulfur. According to the MOI terms of reference, Work Group 2 was to deal with "the transport of air pollutants between source regions and sensitive areas" and calculate how to "achieve proposed reductions in air pollutant concentration and deposition rates which would be necessary in order to protect sensitive areas." The terms of reference do not mention any specific pollutant. But Work Group 2 modeled the transport and deposition of sulfur only. The nitrogen system, the other major contributor to acidity in deposition, was not included. Other gaseous and particulate pollutants which are proven to be or are potentially injurious (ozone, organics, metals, etc.) were relegated to a single chapter in the Final Report. In so doing, any relations between these pollutants and sulfate or acidity were never clarified. By delving deeply into the transport of these other substances, much could have been learned about transport of acidic materials. Instead, the "other pollutants" were used merely as additional examples of materials which can be transported across political borders. An interesting class of problems not considered by Work Group 2 is how pollutants interact to produce a given effect.

In great contrast to wet deposition of sulfur and nitrogen, which is now being measured routinely and accurately at many sites in North America, dry deposition is far behind. Reliable techniques are still being developed; very little quantitative information is available. From quantitative measurements in a few calibrated watersheds (Hubbard Brook in New Hampshire, for example), it is clear that dry deposition of sulfur is important, because more sulfur arrives at the surface than can be accounted for by precipitation alone. But measurements of this type are time-consuming, and hence too scattered to have provided any general picture of dry deposition. Without accurate dry-deposition velocities, transport models are hardly more than educated guesses.

Confusion about the definition of "linearity" is common in discussions of acid deposition. To its credit, Work Group 2 adopted a strict definition and used it consistently. Unfortunately, though, the difference between this definition and the more common colloquial use of "linearity" was not given. As a result, Work Group 2's discussion on linearity can be quite hard to follow.

Long-range transport models

Earlier in this chapter we stated that Work Group 2 placed far too much emphasis on long-range transport models as the primary source of information on transboundary transport of acidity. To a large extent, the terms of reference of Work Group 2 forced this emphasis upon its members. The terms of reference of Work Group 2 (reproduced in Appendix 3 of this report) indicate clearly that in August 1980 it was widely held that transport models would soon be the most reliable way to understand

long-range transport. The very first sentence of the Work Group's specific terms of reference shows how central the models were to be: "The Group will provide information based on cooperative atmospheric modeling activities leading to an understanding of the transport of air pollutants between source regions and sensitive areas . . ." Work Group 2 was also to "provide initial guidance on suitable atmospheric transport models to be used in preliminary assessment activities." Only near the end of the terms of reference were traditional scientific methods mentioned, and then in a subordinate way: "assess historic trends of emissions, ambient concentrations and atmospheric deposition to gain further insights into source-receptor relationships for air quality, including deposition." Not only do these terms of reference assign the responsibility strongly to models, they also indicate no doubts that models would succeed. This orientation was even incorporated into the original title of Work Group 2, "Atmospheric Modeling Work Group."

The framers of Work Group 2 were not alone in their optimistic view of models. A similar opinion was elaborated somewhat in the recent OTA (Office of Technology Assessment) report, "The Regional Implications of Transported Air Pollutants: An Assessment of Acidic Deposition and Ozone", Interim Draft, July 1982: "Transport models are the only practical procedure available to estimate the relationship between areas of origin and areas of deposition of long-range transport pollutants. Large-scale regional transport cannot now be measured directly for the large number of sources of emissions and deposition regions of interest, and under the variety of meteorological conditions needed to perform the analysis. Models describing long-range transport of sulfur oxides have been available

for several years; preliminary models of nitrogen oxides transport are just now being developed."

The dominance of transport models was built into the structure of Work Group 2. Although meteorologists and measurement specialists were originally included in the Group, their presence was intended primarily to provide data for the modelers and only secondarily to allow independent assessments of the source-receptor relationship. Subsequently, Work Group 2 was restructured to give a larger role to scientific approaches other than modeling. It was then given a new title, "Atmospheric Sciences and Analysis", which better reflected its new composition. Separate reports on atmospheric sciences and monitoring were issued.

Work Group 2 treated its long-range transport models thoroughly and fairly. Assumptions of the models are well articulated, characteristics of the models are displayed in detail in an extensive table and elaborated in the text, and results are presented both as raw output and in partially digested form. We would have preferred, however, to see the results of the models summarized more fully than they were, and their implications explored more deeply. The Final Reports of Work Group 2 spent too much time comparing the models and not enough time evaluating the meaning of their results.

Final Report 2F comments on the diversity of approaches and parameters in the eight models. We wish to stress again just how different the models can be; the differences have significant consequences. For example, consider the transformation rate of SO_2 to sulfate. While values in all the models average about 1% per hour, some models assume a constant 1% per

hour, others have different rates for winter and summer, and others have diurnally varying rates which can range from 0.1 to 5.5% per hour. Winds are also handled very differently by the models. Some use long-term means or statistics, others calculate them every 3-6 hours; some average through a mixed layer, others use discrete levels. Mean trajectories from Sudbury, Ontario and St. Louis, Missouri during January and July 1978 (Report 2F-M) reflect these differences by showing surprisingly wide divergence between the models. Even the monthly-mean trajectories spread over angles of 30-60°. In one case, the angle was well over 90°, as the trajectory of one model went westward while the others went eastward.

The strengths of transport models are well known and need no further comment here. The important result to be recognized by all who seek to use models as an aid in understanding or as part of decision-making is that their overall performance is still marginal and their value is still limited. In most discussions of models to date, this point has not been stressed. To its great credit, Work Group 2 pointed this out clearly (with the one exception discussed below). The more dominant the role given to models, the more important it is to be fully cognizant of their limitations.

The following limitations of the long-range transport models used by Work Group 2 need to be kept in mind:

(1) With one exception, they consider only sulfur. The roles of nitrogen, ozone and the hydrocarbons, all of which are intimately involved in the atmospheric processing of sulfur compounds, are not considered explicitly.

(2) Only linear chemistry is included. In the real atmosphere, rates of chemical reactions may be highly nonlinear, at least on the small scale. On larger scales of distance and time, however, fluctuations in rate may average to a pseudo-linear behavior. In Chapter 4 of Report 2F, the performance of the transport models relative to the nonlinear ambient system is acknowledged as follows: "The reaction rates are nonlinear with regard to SO_2 because the free radical concentrations are not constant over time and space. The LRT models, therefore, may not correctly predict the quantity and the deposition patterns of H_2SO_4 formed through the gas-phase reactions."

(3) Cloud chemistry, which is now emerging as an extremely important part of the sulfur cycle, is not considered by any of the eight transport models. Work Group 2 has, though, attempted to assess the implications of this new information (the most important of which is that the majority of the oxidation of SO_2 may take place in the aqueous phase in clouds) to control strategies in Chapter 4 of Report 2F. Among other things, they concluded that, "Since the LRT models do not employ the H_2O_2 and O_3 concentration fields, which have important spatial-temporal variations, it is unlikely that they can correctly predict the present quantity and deposition patterns of H_2SO_4 formed through aqueous-phase reactions." Thus, the models cannot handle either gas-phase or aqueous-phase oxidation properly.

(4) Because dry deposition of SO_2 and sulfate cannot be measured at present, their simulation by the transport models cannot be verified. The absence of dry deposition of SO_2 and sulfate, which is now considered comparable to wet deposition of sulfate, is particularly important.

Ultimately, variable dry-deposition velocities will probably be required to simulate long trajectories in eastern North America which pass over areas with different surface characteristics. Only one MOI model incorporated surface-dependent rates of dry deposition (UMACID), and that model was not among the most "successful" ones.

(5) Background deposition is not handled adequately. According to the Executive Summary of Final Report 2F (Chapter 11), "The role of natural or very distant anthropogenic sources of acidity in eastern North America, although likely to be small, remains to be clarified in order to determine what 'background' deposition to use in constructing atmospheric models of source-receptor relationships."

(6) There are meteorological limitations as well. For example, the Executive Summary recognizes one of the well-known problems with air-mass trajectories: "Back air-trajectories analyses are unable to distinguish between near and more distant sources within the same directional sector and cannot be used to trace an air-mass trajectory during periods of weak, variable air flows or over very long distances."

Another meteorological problem is concerned with simulation of air movement at the top of the mixed layer. The eight transport models evaluated by Work Group 2 assumed that emissions were dispersed into the mixed layer, whose top is typically one kilometer, and remained there. In summer, when wet deposition of sulfate is greatest in the Northeast, cumulus clouds commonly draw air out of the turbulent mixed layer and into the more laminar air above. The time required to process a given parcel of air in this way is typically 0.5 to 1 day. Thus, there can be a sink for

SO_2 at the top of the mixed layer which is comparable to or greater than dry deposition at the surface. This upper sink is not included in any of the eight transport models.

Linearity and nonlinearity

The question of "linearity" was given a somewhat confused treatment by Work Group 2. This is unfortunate, because the concept of linearity is extremely important to formulating a strategy to reduce deposition of sulfate. Linearity is used and understood differently in different branches of science, and has colloquial usages which differ from the scientific definitions. To its credit, Work Group 2 chose a single usage and stuck to it. They could have eliminated a great deal of confusion, however, by stressing their definition more and explicitly describing how it differed from other current usages.

Work Group 2 never defined linearity directly. The closest they came was in Appendix 3 of Final Report 2F, where a linear model is defined as one "where all the interrelationships among the quantities involved are expressed by linear equations which may be algebraic, differential, or integral." This is essentially the definition of a linear system as one whose variables are related only by linear equations. To this should have been added the definitions of the three types of linear equations, for there are differences among them. For example, a linear algebraic equation is one whose variables appear to the first power only and have constant coefficients, i.e., cannot involve other variables. In linear differential equations, however, the coefficients of the dependent variable and its derivatives may be functions of the independent variable.

Work Group 2 used linearity in a restrictive fashion. While they allowed the coefficients in a rate equation to contain other variables (see pages 4-1 and 4-2 of Final Report 2F, for example), they required these variables to remain constant. If they did not, the system was considered nonlinear. According to Work Group 2's definition, the sulfur system in the atmosphere will be linear when the rates of its reactions and depositions are first-order in SO_2 or sulfate and have constant coefficients. If, for example, the rate of oxidation of SO_2 is found to involve any other atmospheric species whose concentration can vary (such as the hydroxyl radical) or any meteorological variable such as sunlight or humidity, the sulfur system must be considered nonlinear. By this definition, it is in fact nonlinear, because the oxidation of SO_2 is known to be a complex function of sunlight, moisture and co-pollutants. Alternatively, if the concentration of any sulfur species, in either the atmosphere or deposition, is found to depend on the abundance of any chemical variable, the sulfur system in the atmosphere is nonlinear. (Again, it is clearly nonlinear.)

The problem with this use of linearity is that it corresponds to neither the standard algebraic nor differential definitions given above. It is rather like the algebraic form applied to a differential equation. Work Group 2 should have pointed this out.

Work Group 2's definition of linearity for atmospheric sulfur corresponds to the common, or colloquial, use in which a given change in SO_2 emissions produces the same percentage change in sulfate or sulfate deposition. The recent National Research Council (NRC) report on acidic deposition in eastern North America examined whether the sulfur system

there was linear in this sense. Linearity in the colloquial sense is a critical issue in deciding whether to bear the heavy expense of reducing sulfur emissions nationally. Everybody agrees that the sulfur system is nonlinear in Work Group 2's sense. The important sense is to determine how much one can reduce deposition by reducing emission, i.e., how nearly linear the sulfur system is on the temporal and spatial scales of eastern North America.

An expanded discussion of the effect of scale on (colloquial) linearity would have been useful at this point. On the global scale, the sulfur system is clearly linear, for all the sulfur emitted is deposited (sulfur does not accumulate in the atmosphere the way longer-lived constituents such as carbon dioxide and the Freons do). On the smallest scale, sulfur is highly nonlinear (again colloquially), for it is easily transported away from the point of emission. On intermediate scales, such as the size of eastern North America, the degree of linearity must be intermediate. In this sense, we find the report of the NRC committee most interesting, for it judged the most probable value in the northeast to be 80% linearity, with the range of possible values being 50 to 100%.

The source-receptor relationship

The source-receptor relationship (discussed explicitly in the Regional Modeling Subgroup Report 2F-M) is implicit throughout all the material on modeling. Work Group 2 recognized that this relationship forms the basis of all control strategies for acid deposition, and that the present uncertainties in our knowledge of this relationship may strongly affect recommended courses of action. Thus, Work Group 2's conclusion that the

source-receptor relationship is poorly known beyond the simple demonstration of long-range transport is potent and must be reckoned with. Essentially all the MOI modeling was an attempt to define the source-receptor relationship as well as possible with current tools.

Local vs. distant sources

This important topic is treated fairly in both the Local and Mesoscale Analysis Subgroup Report (2F-L) and the Final Report (2F). The potential importance of local and regional sources, as well as distant sources, is clearly recognized and stated. At the same time, the relative scarcity of data on nearer sources is noted, and more research is called for.

More could have been done, however. Inspection of the transfer matrices of the eight models shows clearly that six of them predict broadly equal contributions from regional and distant sources to suspended and deposited sulfate in the sensitive regions of New York and New England. Even though it is presently impossible to verify these predictions, the similarities from such different models when entire source regions are considered is an important property. This is an example of the kind of result from models which will eventually guide policy.

Effect of uncertainties in emissions on transport models

Chapter 2 of Final Report 2F summarizes the emission data used by Work Group 2 in its regional transport models. The treatment for this topic is brief and straightforward, presumably because emission data for SO_2 is the least controversial aspect of transport modeling. We agree.

Nevertheless, we find the passing reference to uncertainties in emissions--a single sentence near the end of Chapter 2--a bit too casual. Work Group 2 took Work Group 3B's emission uncertainties at face value. We feel that they should have at least commented on them.

In the Final Report of Work Group 3B, the uncertainties in total United States emissions of SO_2 and NO_x are claimed to be less than 3%. For Canada, the figures are estimated at 6 and 10%, respectively. Relative uncertainties in SO_2 emissions from single states range from 10% for the larger emitters to 20% for the smaller emitters. Within a state or province, the uncertainty in emission of SO_2 from a given class of source varies from roughly 15 to 100%, with the largest sources generally having the smallest percentage uncertainties. Uncertainties of individual sources appear to be in the same range. Uncertainties in NO_x emission are generally larger than those for SO_2.

While it is difficult to find any particular flaw in the method used by Work Group 3B to evaluate uncertainties, we feel that the results are generally optimistic. For example, we are extremely reluctant to believe that total United States emission of SO_2 is known to 3%. We also feel that very few point-source emissions are known to 15%.

Nevertheless, uncertainties in emissions are surely much lower than those in other aspects of acid deposition and associated transport models. For example, the best natural emission estimates for SO_2 in eastern North America are at least an order of magnitude smaller than currently estimated anthropogenic emissions. Dry deposition of SO_2, which is commonly believed to be comparable to wet deposition of sulfate, is hardly more than guessed

at for natural ecosystems. Thus, outflow of sulfur to the Atlantic Ocean, which is the difference between total emission in eastern North America and total deposition there, is also not well known. Limitations like this led Work Group 2 to state in its Executive Summary (Chapter 11 of Final Report 2F) that wet deposition, dry deposition, and outflow of sulfur to the Atlantic are all "roughly equal." Considering the large differences in assumptions and parameters of the various transport models, the differences in their results, and the unknown absolute accuracy of any of them, we conclude that uncertainties in regional emissions are not likely to be the limiting factor in developing and evaluating transport models for many years to come.

Remarks on individual reports

Final Report (2F)

The Final Report (2F) of Work Group 2 is a fair and accurate summary of the several supporting documents. It is written well. Many of the remarks of the previous section refer to this report.

The Final Report discusses the various transport models evenhandedly. Their limitations are stated directly. The strengths and weaknesses of transfer matrices are discussed clearly at the outset. Where the report is not intended to justify exhaustively certain aspects of the models (e.g., the discussion of deposition in Chapter 5), it says so.

We recommend that serious evaluation of the results of Work Group 2 be based on its entire product, i.e., the four subgroup reports as well as the Final Report.

Final Report - Atmospheric Sciences Subgroup (2F-A)

The report of the Atmospheric Sciences Subgroup does not pretend to be comprehensive, and should not be judged as such. Rather, it was intended to provide "some information to Memorandum of Intent modelers in areas of particular concern." It consists of four articles. The first two are detailed, thorough and accurate, and were written expressly for the MOI work. The last two, on dry deposition and precipitation scavenging, are executive summaries from the EPA Critical Assessment Review Papers, and were added later. Brief summaries of each are given below.

Paper 1 -"Sulfur and Nitrogen Chemistry in Long-range Transport Models" by J. L. Durham et al.

This paper contains a detailed and accurate summary of homogeneous (gas-phase) and heterogeneous (in water or on solid particles) chemistry of nitrogen and sulfur. Nitrogen chemistry in the presence of hydrocarbons is summarized as follows: "the major observed phenomenon in the system is conversion of NO to NO_2 . . . accompanied by accumulation of O_3." This section contains considerable discussion of various reaction rates, but with no conclusion that any particular values can be applied generally.

The complexities of oxidation of SO_2 are also covered in detail. After concluding that gas-phase oxidation of SO_2 may be dominated by the OH radical in both the clean and polluted troposphere, the writers note that the maximum rates of oxidation of SO_2 observed repeatedly in polluted atmospheres cannot be accounted for even by summed gas-phase reaction rates. Except for organics, the rates of oxidation of SO_2 in droplets are

fairly well understood. Oxidation by H_2O_2 is the only reaction fast enough to produce potentially important amounts of H_2SO_4 in the troposphere. The role of metallic catalysts in aqueous oxidation is still poorly understood. The only important heterogeneous reaction on the surfaces of solid aerosol particles involves soot.

Do field and laboratory studies agree? The paper states that "uncritical acceptance of all of the rates (in a sample calculation) . . . would lead to the SO_2 conversion rate exceeding 40% per hour. However, if only the well-established rates are considered, the SO_2 conversion rate becomes < 1.1% $hour^{-1}$." The uncertainty in this calculation can be contrasted with other statements from this paper: "Field measurements on the rates of SO_2 oxidation indicate that maximum SO_2 oxidation rates of the order of 10% per hour are typical of many atmospheric pollution scenarios," and "the average diurnal rate is 1% per hour." In other words, this paper amply confirms that great uncertainties still exist in the measurements and even in the mechanisms for oxidizing SO_2 to H_2SO_4, and implies that it will be a long time before these uncertainties are removed.

Paper 2 -"The Seasonal Dependence of Atmospheric Deposition and Chemical Transformation Rates for Sulfur and Nitrogen Compounds" by M. Lusis and L. Shenfeld.

A one-sentence summary of this comprehensive collection of seasonal data is given on their page 2-31: "It must be concluded that at present the available plume data is too conflicting to draw any firm conclusions about the seasonal dependence of the SO_2 oxidation rate in plumes."

Paper 3 -"Dry Deposition of Acid Substances" by B. Hicks.

Its opening sentence describes the situation succinctly: "Recent workshops and committee deliberations have agreed that is is not possible to monitor the dry deposition of acidic atmospheric materials directly." The paper also outlines the difficulties and problems in any other technique.

Paper 4 -"Precipitation Scavenging Processes" by J. Hales.

This paper is not actually a product of the United States-Canadian Work Groups, but rather the Executive Summary from the EPA Critical Assessment Review Paper on Acid Deposition.

We note that this review of atmospheric science material (2F-A) was "prepared and compiled for the purposes of providing some background and support for the modeling work" (emphasis added).

Final Report - Regional Modeling Subgroup (2F-M)

This report is well-written and makes its points clearly. Assumptions in techniques and limitations of results are given adequately. The performance of each of the eight models is reviewed in detail. The conclusions drawn are reasonable. The writers were wise to include as much raw data as they did, particularly in light of the critical role that models were expected to play at the outset of the MOI process.

More specific remarks on modeling are given above.

Final Report - Monitoring and Interpretation Subgroup (2F-I)

This is a very good treatise, which generally meets its terms of reference. It is an excellent introduction to the deposition program and its interpretation.

In spite of its length, we have the distinct impression that much of the literature surveyed here is still under-interpreted. (We have the same feeling about much of the other MOI material, as well.) Apparently, the field of acid precipitation is growing so rapidly and its practitioners are so active that it is difficult to find qualified people who have enough time to synthesize it into a coherent whole. This is one of the great needs at present.

The section on "Preliminary data interpretation" seems a bit forced. We would have preferred a briefer treatment of the ways to interpret data, followed by a deeper interpretation of available data. The Monitoring and Interpretation Subgroup had a golden opportunity to illustrate the role that innovative scientific thought can play in the acid-deposition question and should have been given more resources to do so. Considering that this subgroup almost did not exist, though, the product is quite acceptable.

Proper interpretation of monitoring data, however, requires critical attention at each step. For example, the use of single-station sector analysis as an independent way to derive source-receptor relationships has several limitations which may temper one's conclusions: (1) Because many air-mass trajectories are curvilinear, they may originate in a different sector than indicated by their final direction. (2) The method is inherently episodic--conclusions may be influenced greatly by the

selection of incidents. (3) Wet deposition is a function of volume of precipitation, as well as trajectory. (4) Local and distant sources cannot be distinguished by sector analysis alone. It is not clear that the Monitoring and Interpretation Subgroup considered these factors fully.

The section on temporal trends of deposition and its relation to trends in emission could have been expanded and refined. This critical topic needs a great deal more attention and more data. The record is very short.

The treatment of "other substances" was superficial, as it was in the Summary Report. Organic materials were treated better than ozone and metals.

The report offers seven recommendations concerning deposition monitoring. Because a solid data base is so important to understanding deposition, we endorse these recommendations strongly.

Final Report - Local and Mesoscale Subgroup (2F-L)

This report is excellent. Its literature review is thorough and digested. The relevant models and their characteristics are documented in detail. Scientific knowledge and models derived from this evidence are presented in a balanced fashion. The potential weight of local and mesoscale effects relative to long-range effects is shown carefully. The present limitations of local and mesoscale analysis are given, together with recommendations for future work. This fine report should serve as the basis for renewed interest in local and mesoscale effects.

Did Work Group 2 satisfy its terms of reference?

The seven (six originally plus one added later) terms of reference for Work Group 2 are given in Appendix 3 of this report. Three were related directly to transport models. Ironically, we believe that Work Group 2 satisfied the other terms of reference, but not those associated with transport models. In the paragraphs below, we discuss each term of reference.

"identify source regions and applicable emission data bases" This was done satisfactorily, with data supplied by Work Group 3B.

"evaluate and employ available field measurements, monitoring data and other information" This term of reference was met, both by using field studies to help understand transport (Monitoring and Interpretation Subgroup Report) and by using the monitoring data to help evaluate the transport models.

"assess historic trends of emissions, ambient concentrations and atmospheric deposition trends to gain further insights into source-receptor relationships for quality, including deposition" This was done, primarily by the Monitoring and Interpretation Subgroup; however, much more could have been done.

"prepare proposals for the "Research, Modelling and Monitoring" element of an agreement" Thirteen proposals appear in Chapter 11 of Final Report 2F.

"evaluate and select atmospheric transport models and data bases to be used" This term of reference was met in the sense that eight available

transport models were selected for further consideration. To the extent that the performances of the eight models were to be evaluated and at least one selected with confidence for further use, this goal was not met. As stated in the preface to the Regional Modeling Subgroup Report (2F-M), "In view of significant uncertainties in the model input and validation data, which could not be quantified within the time allotted for preparation of this report, no recommendations on the absolute performance of the regional models can be made at this time." In other words, all eight models were considered unverified and unverifiable.

"relate emissions from the source regions to loadings in each identified sensitive area" This task was fulfilled in the narrow sense that calculations were run with each model. Work Group 2 made it quite clear, however, that the results of this exercise were not considered reliable. Thus, this term of reference was not met. For example, the Executive Summary (Chapter 11 of Final Report 2F) states: "The transfer matrices of the different models exhibit variations among the magnitudes of the transfer matrix elements. This variability could lead to substantial differences in the selection of optimum emission reduction scenarios depending upon the particular model applied and the level of detail required. . . . It has not been possible to date to choose a 'best model' among the eight or to produce with confidence a 'best estimate' single transfer matrix for each variable based upon a valid statistical analysis of all model results."

"calculate emission reductions required from source regions to achieve proposed reductions in air pollutant concentration and deposition rates which would be necessary in order to protect sensitive areas" Work Group 2

stated that it had not met this term of reference. According to Chapter 4 of Final Report 2F, "it is unlikely that they (the models) will correctly predict the resulting changes in dry and wet deposition patterns due to reductions in concentrations of SO_2, H_2O_2, or both." From the Executive Summary: "The adequacy of available models to predict the results of alternative emission patterns is uncertain."

In this context, we are puzzled by a statement in the Executive Summary which is both self-contradictory and in opposition to other conclusions of Work Group 2: "Work Group 2 has provided the kind of 'operational tools' required for calculating emission reductions required to achieve concentrations and deposition rates necessary to protect sensitive areas; however, the Work Group has not been able to provide definitive guidance concerning a preferred model or the quantitative degree of confidence that can be placed in any of the individual models." How can a model be an "operational tool" if its accuracy is unknown? Work Group 2 has <u>not</u> provided the kind of operational tools which can be used to select control strategies for SO_2. Work Group 2 has evaluated eight preliminary models, some of which may, with considerable refinement, someday become true operational tools.

Similar conclusions about models have been drawn by others. The OTA report cited above quotes a report by the Utility Air Regulatory Group (UARG) on five transport models to the effect that they "cannot, at the present time, provide adequate information that would assist in distinguishing between policy options." On the other hand, the UARG review also concluded that "the best available methodology currently available for

investigating the transport, transformation, and deposition of atmospheric pollutants on a regional scale involves the use of long-range transport models."

In our opinion, the inadequate performance of the eight transport models should not be considered the fault of the modelers or of the models. The models were the state-of-the-art for that time. Their failure meant merely that they were asked to do too much too soon in their development. This result supported those members of Work Group 2 who maintained from the beginning that decisions for reducing acidic deposition should not be based solely on information which had been processed through models. It now appears that it will be a good many years before transport models will be ready to assume the responsibility accorded them in August 1980 in the MOI terms of reference.

Information from tracers

The outlook for understanding the source-receptor relationship, even when distant sources are involved, may not be as bleak as it would appear from transport models alone. Tracers may provide an independent way to derive such information. To date, the accuracy of transport models has been impossible to verify because sulfate from one region cannot be discriminated from sulfate from another region. But additional substances which can be linked with one or another region offer ways to deduce the regional origins of sulfate in air or in deposition.

Tracers may be pollutants already present (referred to as "natural" tracers in Chapter 8 of Final Report 2F) or substances introduced deliberately. Both types of tracers may be of great value, as acknowledged

in Chapter 8, and are being developed intensively at present. Deliberate tracers, such as SF_6, heavy methanes, or perfluorocarbons, have been exploited longer than the other type, but may be more limited in the long term because they are usually long-lived gases whose atmospheric behavior does not mimic that of the sulfur system. The principal usefulness of these tracers is to study large-scale trajectories and diffusion.

Pre-existing tracers, especially those involving minor elements in the aerosol, may offer more direct information on sources and transport of atmospheric sulfur. Trace elements have been used successfully to determine the relative importances of various sources of urban aerosol. This approach is generally referred to as "urban receptor modeling" or the "chemical element balance" method. Curiously, receptor modeling was not mentioned by Work Group 2. One possible reason is that urban receptor modeling is not directly applicable to acid precipitation, whose scale is hundreds or thousands of kilometers and where regions rather than individual stacks are the relevant sources.

Regional-scale source apportionment for aerosols is developing rapidly. It is now known that aerosols from several source regions in eastern North America have characteristic elemental signatures that can be followed and discriminated hundreds of kilometers downwind. With proper care, the major source areas for secondary constituents such as sulfate can also be determined with reasonable confidence.

It would thus appear that tracer techniques, singly or in combination, offer an alternative way to deduce the source-receptor relationship, and that transport models need no longer be relied upon exclusively.

ACID RAIN PANEL REPORT

VII - REVIEW OF WORK GROUP 3B REPORT - EMISSIONS, COSTS AND ENGINEERING ASSESSMENT

Organization of report

Work Group 3B was given three major charges: to identify control technologies (pollutants unspecified) and determine their costs, to evaluate emissions (present emissions, better estimates of past trends, and most probable future emissions), and to prepare proposals for research and development projects aimed at improved control of emissions. Accordingly, the report is built around these three principal topics. Emissions receive nearly 200 pages of text, control technologies just over 100 pages, and research and development nearly 50 pages. Most attention goes to SO_2, with NO_x second, and all other pollutants a distant third. "Other pollutants" as a group are given less than 30 pages.

General remarks

This report contains a huge amount of information. Clearly, a great deal of work has gone into preparing it. It will be of much use to many persons and agencies.

Unfortunately, however, it contains major flaws which limit its value significantly. The quality of writing and organization is very poor, certainly the worst of the three reports this panel reviewed. This is not just an academic matter, for the report is very difficult to read, understand, and deal with.

For example, the Table of Contents is very difficult to use. The headings are often insufficiently descriptive, if not misleading or wrong.

The organization and titling of the chapters and sections make the report very difficult to use. For example, as Chapter A is currently organized, it is nearly impossible for the reader to sense the true organization of the report as a whole. Chapter B is misleadingly entitled "Trends in Emissions", when its most important section, current emissions, is not a trend. Chapter C, on control technology and costs, should have been so labeled instead of the inappropriate "Emission Source Sectors."

The report has not been carefully edited; it is full of misspellings, poor grammar, and cumbersome expressions. In Appendix 4, the reader is referred to Chapter C for the 1980 emissions, when they are actually in Chapter B. A problem with incorrect word-processing technique following subscripts occurs throughout. Again we stress that the net effect of all these errors is to make Report 3B much less readable than it should be.

The report is more a compendium of facts than a digestion of them. Perhaps this resulted from the size of the task relative to the resources and deadlines. If so, it would be regrettable. We note that this report appeared several months before those of Work Groups 1 and 2 (June 1982 vs. January 1983 and November 1982, respectively).

It is true that matters of emission and control tend to be more cut-and-dried than those of atmospheric transport, transformation, deposition, and interaction with the biosphere, but this is no reason to subjugate critical thought and reasoning to the extent that the writers of report 3B have. For example, we are offered the emission inventory for 1980, together with a detailed discussion on how it and its uncertainties were calculated. For the United States, the probable errors in both SO_2

and NO_x are given as about 3%. These figures are not discussed further, even though they are almost certainly far too low. The projected emissions are not seriously questioned, as they should be. The recommendations for research and development are merely listed, without any attempt to rank them in terms of inherent value, promise, etc. It is widely assumed that emissions are the best-known component of the entire acid-rain phenomenon. The writers of report 3B had an opportunity to comment on this topic, but missed it.

Most importantly, the writers have offered us no statement on what their report means. Decision-makers in both the United States and Canadian governments, who often do not have technical backgrounds, need such a section. As a result of its absence, intermediaries less familiar with the original data will have to try to determine the meaning of this report for them.

Remarks on specific topics

Identifying control technologies and costs

In our view, report 3B identifies all relevant control technologies and assesses their costs reasonably. In this sense, the report is a very useful handbook, although perhaps unduly pessimistic about prospects for improvements in control technologies. Unit control costs (per kilogram of sulfur) vary by nearly a factor of 100, but the report does not develop the implications of this important finding.

Emissions

Methods of calculating past emissions appear to be reasonable, although little detail is given. We note that the report does not say whether its historical trends are considered superior to other published trends, or even different from them. Recall that one of the terms of reference was to generate "improved" historical trends.

The estimates of current emissions also seem reasonable, as do the methods used to arrive at them. As noted above, the uncertainties seem quite low, especially for the United States as a whole. Here the methodology may be questionable. The technique used for combining uncertainties requires errors to be random and nonsystematic; probably neither condition is satisfied in practice. Consequently, we believe that the actual uncertainties may be several times greater than those given in the report.

Concerning projected emissions of SO_2 and NO_x, we note that report 3B offers a single way of calculating each, without documenting that this scenario is indeed the most probable, as specified in the terms of reference. We fully realize the large effort involved in making projections, but feel that their results are insufficiently supported. Reasons for choosing one scenario or model over another should be given. In addition, the effect of variations of several key parameters should be considered, such as the rate of increase in generating electricity, the degree of switching from oil to coal, the extent of replacing older power plants by newer ones with tighter emission controls, and the mix of NO_x

emission characteristics for new vehicles. To the extent that projections are intended to help plan for the future, the effects of reasonable variations in these parameters would be useful.

Concerning research and development, we found it interesting that Work Group 3B spent considerably more effort in identifying and tabulating current projects than it did in proposing new ones or areas of concentration for the future. The list of areas for future research cited here is too long to be regarded neutrally; the projects must be ranked or rated in some way.

The report indicates that per capita emissions of SO_2 are twice as large in Canada as in the U.S., but the implications are not developed.

Did Work Group 3B meet its terms of reference?

Work Group 3B was given six terms of reference, on three topics; one was deleted by the Work Group. We feel that three of the five remaining terms of reference were met. We now list each term of reference and whether it was met:

"identify control technologies, which are available presently or in the near future, and their associated costs" This was met partially. The report lists unit costs, but does not project costs for any abatement scenarios.

"review available data bases in order to establish improved historical emission trends for defined source regions" Some data bases were reviewed; the report does not say whether all were. Historical emission trends

for source regions were produced, but the report does not specify whether they are considered better than earlier trends. Consequently, this term of reference was not met.

"determine current emission rates from defined source regions" This was met satisfactorily.

"project future emission rates from defined source regions for most probable economic growth and pollution control conditions" Emissions were projected from specific source regions under a certain growth pattern and for the present degree of pollution controls. It was not stated whether the conditions for economic growth or pollution control were the most probable ones. Therefore, this term of reference has not been met.

"prepare proposals for the "Applied Research and Development" element of an agreement" This was met satisfactorily, but without any ranking of proposals.

APPENDIX 1

PANELISTS' INSTITUTIONAL AFFILIATIONS AND SCIENTIFIC DISCIPLINES

OFFICE OF SCIENCE AND TECHNOLOGY POLICY
ACID RAIN PEER REVIEW PANEL

Chairman

William A. Nierenberg Director Scripps Institution of Oceanography La Jolla, California	Physicist- Oceanographer

Vice Chairman

William C. Ackermann Department of Civil Engineering University of Illinois Urbana, Illinois	Civil Engineer

Members

David H. Evans Department of Zoology University of Florida Gainesville, Florida	Fish Physiologist
Gene E. Likens Section of Ecology and Systematics Cornell University Ithaca, New York	Ecologist
Ruth Patrick Department of Limnology Academy of Natural Sciences Philadelphia, Pennsylvania	Limnologist
Kenneth A. Rahn Center for Atmospheric Chemistry Studies Graduate School of Oceanography University of Rhode Island Narragansett, Rhode Island	Atmospheric Chemist
F. Sherwood Rowland Department of Chemistry University of California Irvine, California	Atmospheric Chemist

APPENDIX 1, CONTINUED

Members, continued

Malvin A. Ruderman Department of Physics Columbia University New York, New York	Physicist
S. Fred Singer Department of Environmental Sciences University of Virginia Charlottesville, Virginia	Environmental Scientist

Executive Secretary

John K. Robertson Science Research Laboratory U. S. Military Academy West Point, New York	Geochemist

Office of Science and Technology Policy

Tom Pestorius Senior Policy Analyst Office of Science and Technology Policy Washington, DC	Mechanical Engineer

APPENDIX 2

CHARGES OF THE PANEL CHARTER

OFFICE OF SCIENCE AND TECHNOLOGY POLICY
ACID RAIN PEER REVIEW PANEL

1. Committee's Official Designation:

   Acid Rain Peer Review Panel

2. Objectives and Scope of Activities and Duties:

   ° Review the reports of the Working Groups directed by the 5 August 1980 Memorandum of Intent (MOI) on Transboundary Air Pollution between the U.S. and Canada taking into account currently available scientific and technical knowledge on the production, transport, transformation, and deposition of pollutants; the effect of these pollutants on our surroundings, and the economics and engineering estimates of control technology performance.

   ° Provide an assessment of:

   (a) whether the Working Groups have fulfilled their charters under the Memorandum of Intent;

   (b) whether the Working Groups have utilized all significant research and data impacting on their topics in formulating their reports;

   (c) whether the Working Groups' reports:

   (1) clearly identify their assumptions,

   (2) present and discuss alternate theories and explanations,

   (3) provide support of conclusions and recommendations by the data and other evidence considered, and

   (4) address the uncertainties in the available knowledge and its impact on their recommendations.

   ° Provide an independent assessment of the uncertainties in available scientific and technical information on which recommendations of the working groups are based.

   ° Recommend further research and monitoring tasks which will reduce uncertainties in the scientific and technical knowledge.

   ° Provide a written report, with executive summary addressing the above charter.

APPENDIX 3

WORK GROUP STRUCTURE FOR NEGOTIATION OF A TRANSBOUNDARY AIR POLLUTION AGREEMENT[1]

I. Purpose

To establish technical and scientific work groups to assist in preparations for and the conduct of negotiations on a bilateral transboundary air pollution agreement. These groups shall include:

1. Impact Assessment Work Group

2. Atmospheric Modelling Work Group

3A. Strategies Development and Implementation Work Group

3B. Emissions, Costs and Engineering Assessment Subgroup

4. Legal, Institutional Arrangements and Drafting Work Group

II. Terms of Reference

A. General

1. The Work Groups shall function under the general direction and policy guidance of a Canada/United States Coordinating Committee co-chaired by the Department of External Affairs and the Department of State.

2. The Work Groups shall provide reports assembling and analyzing information and identifying measures as outlined in Part B below, which will provide the basis of proposals for inclusion in a transboundary air pollution agreement. These reports shall be provided by January 1982 and shall be based on available information.

3. Within one month of the establishment of the Work Groups, they shall submit to the Canada/United States Coordinating Committee a work plan to accomplish the specific tasks outlined in Part 8, below. Additionally, each Work Group shall submit an interim report by January 15, 1981.

4. During the course of negotiations and under the general direction and policy guidance of the Coordinating Committee, the Work Groups shall assist the Coordinating Committee as required.

5. Nothing in the foregoing shall preclude subsequent alteration of the tasks of the Work Groups or the establishment of additional Work Groups as may be agreed upon by the Governments.

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[1]This is the Annex of the "Memorandum of Intent between the Government of Canada and the Government of the United States of America concerning Transboundary Air Pollution."

APPENDIX 3, CONTINUED

B. Specific

The specific tasks of the Work Groups are set forth below.

1. Impact Assessment Work Group

The Group will provide information on the current and projected impact of air pollutants on sensitive receptor areas, and prepare proposals for the "Research, Modelling and Monitoring" element of an agreement.

In carrying out this work, the Group will:

-identify and assess physical and biological consequences possibly related to transboundary air pollution;

-determine the present status of physical and biological indicators which characterize the ecological stability of each sensitive area identified;

-review available data bases to establish more accurately historic adverse environmental impacts;

-determine the current adverse environmental impact within identified sensitive areas-annual, seasonal and episodic;

-determine the release of residues potentially related to transboundary air pollution, including possible episodic release from snowpack melt in sensitive areas;

-assess the years remaining before significant ecological changes are sustained within identified sensitive areas;

-propose reductions in the air pollutant deposition rates-annual, seasonal and episodic-which would be necessary to protect identified sensitive areas; and

-prepare proposals for the "Research, Modelling and Monitoring" element of an agreement.

2. Atmospheric Modelling Work Group

The Group will provide information based on cooperative atmospheric modelling activities leading to an understanding of the transport of air pollutants between source regions and sensitive areas, and prepare proposals for the "Research, Modelling and Monitoring" element of an agreement. As a first priority the Group will by October 1, 1980 provide initial guidance on suitable atmospheric transport models to be used in preliminary assessment activities.

APPENDIX 3, CONTINUED

In carrying out its work, the Group will[2]:

-identify source regions and applicable emission data bases;

-evaluate and select atmospheric transport models and data bases to be used;

-relate emissions from the source regions to loadings in each identified sensitive area;

-calculate emission reductions required from source regions to achieve proposed reductions in air pollutant concentration and deposition rates which would be necessary in order to protect sensitive areas;

-assess historic trends of emissions, ambient concentrations and atmospheric deposition trends to gain further insights into source receptor relationships for air quality, including deposition; and

-prepare proposals for the "Research, Modelling and Monitoring" element of an agreement.

3A. Strategies Development and Implementation Work Group[3]

The Group will identify, assess and propose options for the "Control" element of an agreement. Subject to the overall direction of the Coordinating Committee, it will be responsible also for coordination of the activities of Work Groups I and II. It will have one subgroup.

In carrying out its work, the Group will:

- prepare various strategy packages for the Coordinating Committee designed to achieve proposed emission reductions;

-coordinate with other Work Groups to increase the effectiveness of these packages;

-identify monitoring requirements for the implementation of any tentatively agreed-upon emission-reduction strategy for each country;

-propose additional means to further coordinate the air quality programs of the two countries; and

-prepare proposals relating to the actions each Government would need to take to implement the various strategy options.

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[2]Work Group 2 added another specific term of reference to its work and inserted it between the fourth and fifth terms of reference given here. It reads (Work Group 2 Final Report, Appendix 1, pg. A1-2): "evaluate and employ available field measurements, monitoring data and other information."

[3]Work Group 3A did not publish a final report.

APPENDIX 3, CONTINUED

3B. Emissions, Costs and Engineering Assessment Subgroup

This Subgroup will provide support to the development of the "Control" element of an agreement. It will also prepare proposals for the "Applied Research and Development" element of an agreement.

In carrying out its work, the Subgroup will:

-identify control technologies, which are available presently or in the near future, and their associated costs;

-review available data bases in order to establish improved historical emission trends for defined source regions;

-determine current emission rates from defined source regions;

-project future emission rates from defined source regions for most probable economic growth and pollution control conditions;

-project[4] future emission rates resulting from the implementation of proposed strategy packages, and associated costs of implementing the proposed strategy packages; and

-prepare proposals for the "Applied Research and Development" element of an agreement.

4. Legal, Institutional and Drafting Work Group[5]

The Group will:

-develop the legal elements of an agreement such as notification and consultation, equal access, non-discrimination, liability and compensation;

-propose institutional arrangements needed to give effect to an agreement and monitor its implementation; and

-review proposals of the Work Groups and refine language of draft provisions of an agreement.

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[4]Work Group 3B deleted this specific term of reference from its work (Work Group 3B Final Report, Appendix 1, pg. A-2).

[5]Work Group 4 did not publish a final report.

APPENDIX 4

MATERIALS PROVIDED TO THE PANEL

September 1982 - Work Group 3B Final Report, dated June 1982.

- Outlines of each Work Group's report and lists of the United States and Canadian members in each Work Group. Prepared by the Executive Secretary.

October - November 1982 - Interim Draft of "The Regional Implications of Transported Air Pollutants: An Assessment of Acidic Deposition and Ozone", Office of Technology Assessment, dated July 1982.

- Work Group Reports as follows:

Work Group 1

- Phase I Interim Report, dated February 1981.
- Phase II Interim Working Paper, dated October 1981.
- Phase III Draft Report, marked by the United States Co-chairman to indicate sections not yet agreed to by the Work Group, not dated.

Work Group 2

- Phase I Interim Report, dated January 1981.
- Addendum to Appendix 8 - transfer matrices of the Phase I Report on Atmospheric Modeling, dated 6 February 1981, revised 10 July 1981.
- Atmospheric Transport and Deposition Modeling: Inventory, Analysis and Recommendations, dated December 1980, revised June 1981.
- Phase II Working Report (2-15), dated 10 July 1981.
- Atmospheric Sciences Review (2-14), dated 10 July 1981.
- Modeling Subgroup Report (2-13), dated 10 July 1981.

APPENDIX 4, CONTINUED

- Model Profiles
  - Documentation of the Atmospheric Environment Service Long-Range Transport of Air Pollutants Model AES-LRT (2-5), dated 15 May 1981.
  - Documentation of the Advanced Statistical Trajectory Regional Air Pollution Model ASTRAP (2-6), dated 12 May 1981.
  - Documentation of the Eastern North American Model for Air Pollution ENAMAP (2-7), dated 30 June 1981.
  - Documentation of the Ontario Ministry of the Environment Statistical LRT Model OME-LRT (2-8), dated 31 March 1981.
  - Documentation of the University of Michigan Atmospheric Contribution to Inter-Regional Deposition Model UMACID (2-10), dated 24 June 1981.
  - Documentation of the Transport of Regional Anthropogenic Nitrogen and Sulfur Model MEP-TRANS (2-11), dated 30 June 1981.
  - Documentation of The Capita Monte Carlo Model MCARLO (2-12), dated 30 June 1981.
- Phase III Draft Report 2F, dated 15 October 1982.
- Atmospheric Science Review Sub-group Report, 2F-A, dated 15 October 1982.
- Local and Mesoscale Analysis Subgroup Report, 2F-L, dated 15 October 1982.
- Monitoring and Interpretation Subgroup Report, 2F-I, dated 15 October 1982.
- Regional Modeling Subgroup Report, 2F-M, dated 15 October 1982.
- Replacement pages for the four subgroup reports, dated 11 November 1982.

Work Group 3A

- Interim Report, dated January 1981.

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Work Group 3B

- Interim Report, dated 15 January 1981.

- Draft copy of "High-Leverage Investment in the Atmospheric Sciences and Related Disciplines", paper by the Committee on Science, Engineering and Public Policy, National Academy of Science, dated 22 October 1982.

- Draft of EPA Critical Assessment Document, Volumes 1 and 2, dated October 1982.

2 February 1983 - Drafts of "Modeling Uncertainty About Carbon Dioxide" and "A Review of Estimates of Future Carbon Dioxide Emissions", papers for review by the Carbon Dioxide Assessment Committee, National Academy of Science.

2 March 1983 - Work Group 2 Final Report, dated 15 November 1982.

- List of differences between the above report and the draft given to the panel in November 1982. Prepared by the Executive Secretary.

- Model Profile

  - Documentation of the Regional Climatological Dispersion Model RCDM-2 (2-9), dated September 1982.

29 March 1983 - Work Group 1 Final Report, dated January 1983.

- List of differences between the above report and the draft given to the panel in November 1982. Prepared by the Executive Secretary.

April 1983 - Executive Summaries - Work Group Reports, dated February 1983.

May 1983 - Public Comments:

  - American Petroleum Institute: "Role of Organic Litter in Lake Acidification and Buffering"; "Using Historical Data to Ascertain Lake Water pH Trends"; "Comments on the MOI Emission Inventory"; "Total Primary Sulfate Emissions"; "Emissions Projections for Industrial Boilers"; "Comments on the MOI Emission Inventory Uncertainty Estimates".

  - Everett and Associates: "Comments on Section 3, Aquatic Impacts".

APPENDIX 4, CONTINUED

- Hunton and Williams, on behalf of the Utility Air Regulatory Group: "Review and Critique of the Work Group 1 Phase II and Phase III Impact Assessment of the U.S.-Canadian Transboundary Treaty Negotiations"; "Review and Critique of the Work Group 2 Phase II and Phase III Modeling Activities of the U.S.-Canadian Transboundary Treaty Negotiations"; "Comments on the Final Report of Workgroup 3B".

July 1983 - "Acid Deposition in North America - A Review of the Documents Prepared under the Memorandum of Intent between Canada and the United States of America, 1980, on Transboundary Air Pollution - II Technical Report", prepared by the Royal Society of Canada for the Government of Canada, dated May 1983.

October 1983 - "The Ups and Downs of Acid Rain". Preprint by Fred Singer.

- "Observations in German Forests during the Late Summer of 1983", memorandum from Dr. Ellis Cowling, dated 7 October 1983.

- The following papers, most translated from German, were offered to the panel:

  - "Devastating effect of acid rain on forests described." Stern, 28 October 1982, pp. 35, 36, 38.

  - "The Disease Picture--Different Species of Trees, but Identical Symptoms," by Peter Schuett. Bild der Wissenschaft 12: 86-101, 1982.

  - "Air Pollution--A Danger to Trees for over 100 years now," by Karl Friedrich Wentzel. Bild der Wissenschaft 12: 103-106, 1982.

  - "Die Versauerung - Giftstoffe Reichern Sich An," by Bernhard Ulrich. Bild der Wissenschaft 12: 108-119, 1982.

  - "Production and Consumption of Hydrogen Ions in the Ecosphere," by B. Ulrich. In Effects of Acid Precipitation on Terrestrial Ecosystems, pp. 255-281. Edited by T. C. Hutchinson and M. Havas. New York: Plenum Press, 1978.

  - "Theoretical Consideration of the Ion Cycle in Forest Ecosystems," by B. Ulrich. Z. Pflanzenernaehr. Bodnek. 144 (6): 647-659, 1981.

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- The Destabilization of Forest Ecosystems by the Accumulation of Air Contaminants," by B. Ulrich. Der Forst und Holzwirt 36 (21): 525-532, 1981.

- "Balances of Annual Element Fluxes Within Forest Ecosystems in the Solling Region," by E. Matzner and B. Ulrich. Z. Pflanzenernaehr. Bodenk. 144 (6): 660-681, 1981.

- "Dangers for the Forest Ecosystem Due to Acid Precipitation - Necessary Countermeasures: Soil Liming and Exhaust Gas Purification," by B. Ulrich. Preprint.

- "Appendix 3 - Explanations for Filling Out the Form 'Recording Forest Damage'." Preprint.

- "Chemical Changes Due to Acid Precipitation in a Loess-Derived Soil in Central Europe," by B. Ulrich, R. Mayer, and P. K. Khanna. Soil Science 130 (4): 193-199, 1980.

APPENDIX 5

BENEFIT-COST ANALYSIS APPLIED TO THE ACID RAIN PROBLEM

S. FRED SINGER

Before making any decisions or taking actions, it is natural to inquire about the benefits following from these actions and the cost involved. This kind of reasoning applies to both public and private decision-making. But public decision-making, in addition, involves the concept of equity, the consideration of whether those who are paying the cost of certain actions are also receiving all or most of the benefits.

Equity considerations aside, one needs some estimate of costs and benefits, expressed in similar units, so that one can make a comparison. It is most convenient, but not always easy, to express the benefits and costs in monetary units. Much progress is being made in quantifying benefits in areas which are usually considered to be unquantifiable--not only health effects but also improvement in visibility, aesthetic effects, and the like.

When weighing benefits against costs, it is not sufficient to have the benefits large enough to be commensurate with the costs, i.e., to have the benefits approximately equal to the costs. All this means is that the net benefits, that is, the difference between benefits and costs, are zero. But that same result can always be obtained by doing nothing, in which case assuredly the benefits as well as the costs would be zero; hence, the net benefits would also be zero.

What we would like to do, in principle at least, is to make the net benefits as large as possible. A simple theoretical discussion tells us

that this is equivalent to a situation where the incremental benefits resulting from a particular action are equal to the incremental cost. This can be seen as follows. If incremental benefits were greater than incremental costs, then it would pay to continue with our actions and thereby increase the net benefits. On the other hand, if incremental benefits are less than incremental costs, then we have gone too far. Figure 1 demonstrates this principle of marginal benefit-cost analysis.

Most of the costs are usually incurred as capital costs in the initial period, while the benefits may extend over a longer period of time. It is necessary, therefore, to "discount" both the costs and benefits to the same year, say to the present, with the use of an appropriate interest rate, in order to carry out our analysis. This is a detail perhaps, but it can be important.

More generally, "dynamic" benefit-cost analysis deals with the problem of optimization in the presence of many sources of pollution, with only some of them--usually the new ones--subject to stringent controls. Under those conditions, large sums can be invested without any immediate benefits. (See, e.g., Fig. 2). The classic example is automobile pollution where great pollution control costs may be incurred for new cars initially, but where there can be no substantial improvements in air quality until almost all of the old cars have disappeared from the fleet. This is a general problem where one has facilities that are "grandfathered," for example, grandfathered electric utilities and grandfathered industries, which are not required to control their pollution to the same degree as new plants. Thus,

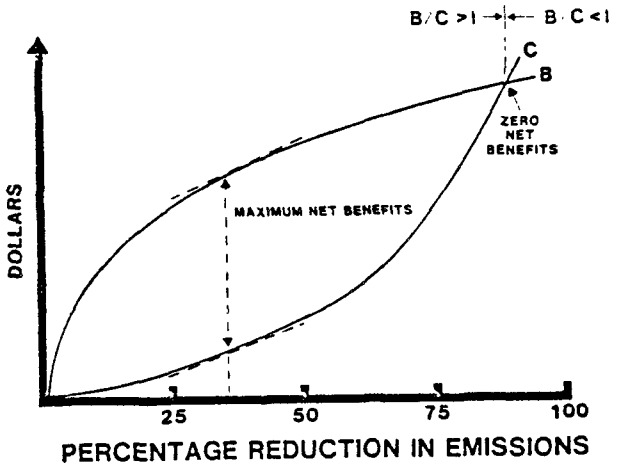

FIGURE 1. Typical costs and benefits associated with increasing reductions in emissions. Note that zero net benefits, i.e. B-C occur both if nothing is done (i.e., zero reduction) and for large reductions (where the benefit-cost ratio B/C is 1). Maximum net benefits occur somewhere between these two cases.

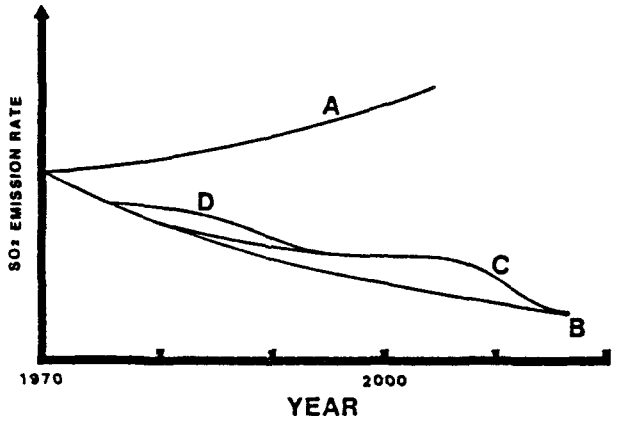

FIGURE 2. Emissions of SO_2 as a function of time. Curve A: without emission controls. Curve B: with controls, emissions gradually declining. However, the imposition of extreme new source performance standards (NSPS) can produce a perverse effect (Curve C) by encouraging the continued operation of older power plants that do not have to comply with NSPS. Curve D shows the effects of the 1977 Clean Air Act Amendments which actually encouraged the use of higher sulfur coal. (All curves are drawn schematically.)

there is an incentive to make old plants last longer, because if they are not required to have pollution control equipment they are cheaper to operate. Dynamic benefit-cost analysis also takes into account that there may be other sources of emissions, including natural sources, so that working on only one industrial pollution source, like electric utilities, may not be optimal.

Benefits

When we apply this analysis to the acid rain problem, we can identify a number of benefits which would result if acid deposition were to diminish. Many of these benefits have been described in the Work Group 3B Report, but they have not been evaluated or even estimated. They could include recreational fisheries, commercial fisheries, the aquatic ecosystem generally, agriculture, forestry, the general preservation of the ecosystem, water supply for various human uses, effects on buildings and structures, atmospheric visibility, and, finally, human health (morbidity and mortality).

Benefit analysis proceeds in two steps: (1) one estimates how much reduction in damage would result if acid deposition were to be decreased by a certain percentage, say ten percent; and (2) one judges what an emission reduction of, say, one million tons of sulfur dioxide per year implies in terms of reduced acid deposition--at a particular SO_2 emission level. Step 1 is within the province of Work Group 1. Step 2 belongs to Work Group 2, and involves the well-known scientific complications having to do with (a) the degree of mixing as opposed to advection; (b) the degree of conversion of SO_2 into sulfuric acid, including questions of nonlinearity

and saturation effects; and (c) the presence of other pollutants, whether man-made or natural, which produce similar final effects.

It is important to make some rough, even order-of-magnitude estimates. One should at least be able to decide which effects (or benefits) are more important and which are of lesser importance. The methodologies for making such determinations are available but the work has not been done. For example, one methodology which is useful in many situations is to estimate benefits by measuring "willingness to pay." Into this category falls the topic of "liming," whereby lime is applied to lakes or water supplies in order to reduce the acidity of the water. From the cost of the liming effort, one can at least derive a lower limit to the benefits which come about with reduced acidity.

Costs

Estimating the control costs of emissions which are thought to be the precursors of acid deposition is also a difficult subject, but perhaps not as difficult as estimating benefits. Cost estimates require knowledge in areas of technology and atmospheric science.

First of all, it is important to know what technologies can be brought to bear for the removal of, say, sulfur at different stages in the combustion process, ranging from cleaning coal and removing sulfur during burning, to removing SO_2 from flue gases. Because of the rapid evolution in technology and because of uncertainties about reliability and costs of different technologies, such knowledge is often hard to come by.

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The Work Group 3B Report addresses this matter, but is not altogether hopeful about the efficacy and reliability of control devices. It is our view, after reviewing research in progress and consulting industry experts, that the technical problems can and will be solved. According to this view, the unit cost of pollution control should stabilize or even decrease in the future.[1]

The other quantitative input relates to dispersion of emissions, their conversion into acids, and eventual deposition. Here, however, one may proceed in steps, starting with the simplest model and proceeding to more complicated ones. Certainly the simplest model is that of a "single box" in which emissions from the eastern United States and Canada are received. In this box model, reduction of emissions from a source anywhere has the same value as reduction of emissions from another source. The problem then simply becomes that of reducing SO_2 emissions from all present sources and future sources as well.

A more realistic approximation, yet still quite simple, could divide the transport problem into two parts: (1) local, i.e., less than 300 miles from the source; and (2) distant, i.e., greater than 300 miles. One would then argue that all sources in one "box" contribute a certain fraction of their emissions to distant pollution, with the fraction being the same for all sources.

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[1]There may, however, exist a serious pollution problem in the disposal of the slurry-like waste material from flue gas desulfurization.

Least-Cost Approach

Borrowing the concept of the "bubble," which is now widely used to allow emissions trading within any given plant, it may be possible to apply emissions trading to the whole region so that a least-cost approach to the reduction of emissions can be put into effect. It is interesting that many people are coming to this conclusion.[2] Setting aside for a moment the question of who pays for the control of pollution--ultimately always, of course, the consumer--pollution control can then be achieved by the least-cost method. This means that, initially, sulfur will be removed by simple washing of coal (thereby removing the inorganic sulfur in pyrites) and by pollution control in presently uncontrolled smelters. As noted by Work Group 3B, these techniques cost (per kilogram of sulfur removed) only a few percent of the cost of flue-gas scrubbing in a power plant burning low-sulfur coal, yet a kilogram of sulfur removed by any method should have an equivalent effect on air quality, according to the simple box model.

The approach just described is in strong contrast to the following scenario which is economically quite inefficient. The argument is often made that since pollution control is expensive, it is best to apply it to industries that can afford it or that can easily pass along the costs. It is argued that pollution control on smelters would make them noncompetitive

[2]For example, David Hawkins, former EPA Assistant Administrator for Air Quality in the Carter Administration, writing in AMICUS, proposes a wider bubble approach.

and put them out of business, but that control on utilities might add only a few percent to the electricity bill of their customers. But if it costs the utility 100 times more to remove a kilogram of sulfur as it does the smelter, wouldn't it make more sense to ask the utility customers to pay the smelters to remove the sulfur?

A practical way of achieving the least-cost approach to pollution control is to introduce what are called transferable emission rights. This would guarantee that the market will work in such a way as to achieve the lowest-cost methods of removing pollution.[3] A central authority, presumably the government, would have to decide how much sulfur may be admitted into the atmosphere, based on some benefit-cost considerations. By limiting the number of rights sold or made available by other means, one can control exactly the amount of sulfur emitted. The rights can either be given away, for example to existing polluters who would be grandfathered, or they could be auctioned off so as to create greater equity as well as a source of money for the Treasury. The only important matter for the least-cost approach is that rights be issued and that they be transferable.

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[3]The present approach of prescribing ultrastrict performance standards for new sources is extremely costly and wasteful to society. A recent report by the Congressional Budget Office shows that emission trading would lower considerably the cost of SO_2 abatement (The Clean Air Act, The Electric Utilities, and The Coal Market, April 1982).

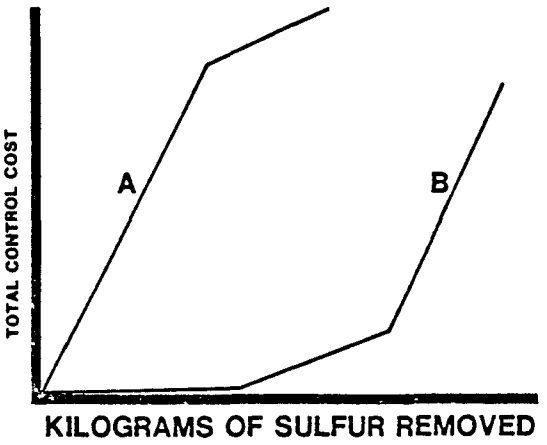

FIGURE 3. Control costs vs. increasing reduction in SO_2 emissions. The slope of the curves gives the cost per pound of sulfur removed. Curve A illustrates the approach mandated by present legislation, focussing on BACT (best available control technology), such as flue gas desulfurization. Curve B illustrates schematically a "least-cost" approach which starts with lowest-cost methods, such as low-sulfur coal or coal washing, before proceeding to higher-cost approaches.

To take an actual example, smelters would be inclined to sell their rights to the utilities and use the money to control their pollution. Smelters might even make some money because they can remove their pollution at very little cost and they can sell their rights at a higher price. The overall result would be to achieve the desired reduction of emissions at the lowest cost to society as a whole or a much higher degree of pollution control with no more money spent overall.

Conclusion

In the absence of even order-of-magnitude estimates of economic damage attributable to acid deposition, and with emission control costs certainly in the multibillion dollar range, one must question whether we are attacking a million-dollar problem with a billion-dollar solution.

An additional caveat derives from the present scientific uncertainties: Will a reduction in emissions produce proportionate reductions in deposition and in the environmental impacts believed to be associated with acid deposition?